THE REPORT OF THE WORKING GROUP ON AIR QUALITY IN THE TORONTO SUBWAY SYSTEM

ARB-TDA-Report No. 12-80

MARCH 1980

Ontario

Ministry
of the
Environment

Ministry
of
Labour

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ONTARIO MINISTRY OF THE ENVIRONMENT

ONTARIO MINISTRY OF LABOUR

TORONTO TRANSIT COMMISSION

MARCH 1980

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MEMBERS OF THE WORKING GROUP

The Working Group on Air Quality in the Toronto Subway System consisted of the following members:

From the Ontario Ministry of the Environment:

Dr. F. Frantisak (Member and Chairman 1976-1977)
Dr. R. Caton (Chairman 1977-1980)
Mr. D. Ogner
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Mr. J. Townsend
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ACKNOWLEDGEMENT

The members of the Working Group wish to thank their many colleagues on the staffs of the three participating organizations for their cooperation during the course of this study.

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1.0 SUMMARY

1.1 Abstract

This is the final report of the Working Group on Air Quality in the Toronto Subway System. The Working Group consisted of representatives from the Ontario Ministry of the Environment, the Ontario Ministry of Labour, and the Toronto Transit Commission. It was formed in August 1976 to direct studies of air quality in the subway system; to evaluate the results with regard to health effects on both passengers and subway employees; and to recommend any necessary abatement measures.

Several studies of air quality, human exposure, and equipment operating and emissions characteristics were carried out between October 1976 and April 1978. These studies are described and their results interpreted in this report.

Conclusions are reached concerning air quality in the subway system and possible effects on human health of contaminants in subway air. The Working Group finds current subway air quality acceptable according to criteria, standards, and guidelines established for both occupational and environmental health. Nonetheless, a supervised abatement program was begun in 1978 to reduce emissions into subway air, primarily from subway train brake shoe wear. This program, implemented during the course of the study, was expected to achieve a measurable improvement in subway air quality by the end of 1979.

To the Working Group's knowledge, the studies described in this report are the most exhaustive of any conducted to date in a subway transit system.

1.2 Conclusions

The Working Group on Air Quality in the Toronto Subway System has reached the following conclusions:

1) There is no discernible health hazard either to TTC employees or to passengers due to the contaminants that are found in subway air, although subway passengers were found to be exposed to higher levels of airborne particulate matter than the general public in Toronto.

   Total suspended particulate matter and its components, lead and asbestos, were the air contaminants singled out for special attention because of their potential to cause adverse health effects.

2) The measured levels of contaminants were assessed relative to existing Ontario Environmental Air Quality Criteria or Guidelines and Occupational Health Guidelines for all of the detected components of airborne particulate matter that were of concern. The conclusion that there is no discernible health hazard to passengers (1 above) is based upon consideration of measured levels relative to the criteria or guidelines and of the short-term exposure of subway passengers relative to the 24-hour exposures upon which the environmental criteria or guidelines are based.

   The conclusion respecting employees (1 above) is based upon normal application of the occupational health guidelines for worker exposure, supported by biological monitoring.

3) The predominant emissions of particulate matter in the subway system are due to normal wear of brake shoes, subway car wheels, and rails. Brake shoe emissions comprise approximately one-half of measured airborne particulate matter. The greatest quantity of brake shoe emissions is given off by the original Gloucester ('G') cars, which are currently in use only on the Yonge-University-Spadina line.

4) Measured levels of pollutants are greater in those sections of the system on which 'G' cars are used, and where heavy braking is required, namely, the North Yonge and University sections. Lesser contamination from brake shoe emissions occurs in the Lower Yonge section. Much less contamination was found in the Bloor-Danforth section. The air quality studies covered by this report were completed before the Spadina section opened (January 1978), so that the report contains no data relating specifically to air quality in that portion of the subway system.

5) A significant reduction in particulate emissions has been achieved by converting the brake shoes of the 'G' cars to a type that (a) wears nearly twice as long as the older type and (b) contains practically no lead. All of the 134-car 'G' fleet had been converted as of the end of 1979.

6) The opening of the Spadina section has helped to improve the air quality of the Yonge and University sections. This improvement arises from the fact that the additional cars acquired to meet increased fleet demands are of the new 'H' type. The proportion of 'G'-type cars in the system has been reduced and so has the relative contribution of their brake shoe particulate emissions.

1.3 Recommendations

The Working Group makes the following recommendations, based on the results of studies described in this report and on other available information:

1) Although there are no current or imminent health hazards that may be attributed to airborne contaminants in the subway system at the concentrations that have been measured, action to reduce the concentrations of lead, asbestos, and suspended particulate matter in subway air should continue. This action will improve subway air quality for both passengers and employees.

2) The abatement objectives for all contaminants should be to reduce typical levels on the Yonge-University-Spadina line to levels similar to those found currently on the Bloor-Danforth line as soon as is practicable, using the best available technology.

3) Implementation of a specific abatement program to achieve the objective set out above should be continued by the TTC in accordance with Ministry of the Environment guidelines.

4) Air quality in the subway should be monitored regularly by the TTC at one or more sites, in co-operation with the Ministry of the Environment.

5) Progress on the continuing abatement program and monitoring should be reported at the end of 1980, and the report made public.

6) Although TTC employees are not being exposed to high levels of asbestos and lead, it is recommended that periodic personal monitoring of TTC employees, utilizing individual (personal) air quality monitoring equipment, be carried out in accordance with Ministry of Labour guidelines.

7) The Working Group should be disbanded with the publication of its final report.

2.0 INTRODUCTION

2.1 Background

In May 1975 two high-volume filter samples were collected in the subway system of the Toronto Transit Commission (TTC) as part of a province-wide survey for airborne asbestos conducted by the Ministry of the Environment (MOE). The subway was chosen to test whether emissions from normal wear of brake shoes containing asbestos were contaminating the enclosed spaces of the system. Analyses showed that asbestos levels were higher than typical ambient air concentrations.

Twelve additional airborne particulate matter samples were collected in the TTC subway in April 1976. The analysis of these samples confirmed the presence of chrysotile asbestos in subway air, and this, combined with the apparently high suspended particulate matter loading (assessed by visual observation), prompted plans for an intensive study of general air quality in the subway system. The results of both the May 1975 and April 1976 surveys are summarized in Appendix E.

2.2 The Working Group

In August 1976, a working group was formed to oversee and evaluate any additional air quality surveys and any follow-up monitoring activities that resulted. Group members were provided by:

Toronto Transit Commission (TTC)

Ontario Ministry of Labour (MOL)*

Ontario Ministry of the Environment (MOE)

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* Prior to December 1976, members of the Working Group representing the Occupational Health and Safety Division, MOL, were with the Ministry of Health.

2.2.1 Terms of Reference:

The initial terms of reference for the working group were as follows:

1) to coordinate MOE/MOL/TTC studies of subway air quality with respect to airborne particulate matter, especially asbestos fibre content;

2) to assess data resulting from past and future surveys of subway air quality;

3) to make recommendations to managements of participating agencies concerning the need for, and the nature of, abatement action.

More detailed terms of reference were developed later as follows:

4) to prescribe acceptable methods of sampling and analysis for both occupational and environmental exposure;

5) to analyze collected particulate matter for parameters other than asbestos;

6) to sample ambient air adjacent to points of air emissions from the subway;

7) to determine the sources of asbestos and other emissions in the subway air;

8) to investigate any other matter that the Working Group considered pertinent.

2.2.2 Objectives of the Study

The objectives of assessing the subway air quality were as follows:

1) to determine the sources of particulate emissions into subway air;
2) to determine whether the degree of contamination of subway air was creating a potentially harmful human exposure;
3) to determine which abatement measures would lead to reduced emissions and improved air quality.

2.2.3 Program Design

The results of the May 1975 and April 1976 surveys were insufficient to quantify the emission sources of asbestos in the subway atmosphere, but two sources were suspected: (1) fibres released during the braking process from the brake shoes, (2) fibres dislodged from the tunnel lining material in particular sections of the subway by wind erosion. At this point, when the working group was formed, the focus of the study was broadened to include general air quality, especially total suspended particulate matter (TSP) and identification and quantification of its components.

The program designed by the Working Group was based on the two previous investigations of air quality and included the following components:

1) Detailed elemental analysis of brake shoes (various compositions) and tunnel lining material (various compositions) were performed to estimate their emission potential of asbestos, lead, and other components of the particulate matter. An on-going TTC materials test program evaluated substitute brake shoe materials.

2) An intensive field survey (October 1976) was designed to determine the subway contaminants, their sources, and public and

employee exposure.

3) Follow-up studies were performed based on information from the intensive survey to evaluate the effectiveness of abatement measures, to achieve a more accurate quantification of emission sources, and to determine employee health risk.

The complete program, as carried out under the direction of the Working Group, was as follows:

1) Comprehensive field survey in the TTC Subway System (October 18-22, 1976)

2) Follow-up surveys:

   i) Wall washing experiments (February 8-22, 1977)

   ii) Demonstrating effect of different types of subway cars (April 21 - May 10, 1977)

   iii) On-train air sampling experiments (August 16-17, 1977)

   iv) Personnel sampling survey (September 6-7, 1977)

   v) Employee blood lead-level survey (April 3, 1978)

3) On-going program:

   Evaluation of different types of brake shoes for subway cars (since 1975).

3.0 OPERATION OF TTC SUBWAY

3.1 Summary of Operations Affecting Air Quality

3.1.1 Environmental Factors

An excellent summary of subway environmental and design factors appears in "Subway Environmental Design Handbook," second edition, published by the U.S. Department of Transportation. Portions of this report are reproduced in Appendix A.

In the report, the following factors, which affect the human environment in a subway, are cited:

1) temperature and humidity
2) air quality
3) air velocity and rapid pressure changes.

The second factor was the subject of the Working Group's activities.

3.1.2 Air Quality

Air quality in a subway system, just as ambient air quality, depends upon the amounts and rates of introduction of various contaminants into the air and the rates at which these concentrations can be reduced by dilution with relatively clean air (i.e., ventilation). In short, air quality can be controlled by limiting emission rates or by increasing ventilation rates.

3.1.2.1 Ventilation

In the ambient atmosphere, the dispersion of contaminants depends entirely on meteorological conditions. In buildings or the enclosed portion of a subway system, air quality can be modified by mechanical means of ventilation.

In the TTC subway, ventilation in the tunnelled portion is

achieved primarily by the normal movement of trains. Air is forced to move through the tunnel system by the piston-like action of a .train, which produces compression ahead and suction behind as it travels. The ventilation shafts, because of their design, act as exhausts of tunnel air when the motion of the train compresses the air ahead of it and as intakes when the suction effect takes over. There is no mechanically assisted movement of air in the ventilation shafts.

An auxiliary fan and vent shaft system in the TTC subway provides ventilation when train movement is stopped (i.e., in emergencies such as mechanical or electrical equipment failure or fire). These fans may also be used to increase ventilation under normal operating conditions when the temperature inside the system becomes discomforting because of high ambient air temperature.

The ventilation design criterion for the TTC subway requires a complete change of air in the enclosed portion of the system roughly three times per hour under normal operating conditions.

3.1.2.2 Potential sources of Air Contaminants

Previous studies of subway equipment performance indicated that airborne particulate matter would be the primary contaminant of concern. The following discussion of specific emission sources in the TTC subway, therefore, is confined to particulate matter.

The major potential emissions of contaminants within the subway system arise from the normal wear of materials caused by friction and wind erosion. The following emission sources were expected to be the most important:

1) wear of the subway car steel wheels and steel rails and "third rail" electrical power contacts;

2) wear of the brake shoes (composition friction material) during the braking process;

3) wind erosion of tunnel facing or lining material.

Polluted outside air, entering the system through the ventilation shafts, may also contribute to contamination of subway air. This aspect was evaluated in the October 1976 survey. After the generated dust has settled, re-entrainment caused by high velocity winds created by train movement might also be a problem.

3.1.2.2.1 Wheel and Rail Wear

In order to propel the trains and stop them, drive wheels on subway cars must have traction with respect to the rails. When the trains move, especially during acceleration and deceleration, friction and grinding forces between wheels and rails cause material wear. Since the wheels and rails are made of steel, wear will produce emissions of small iron particles.

3.1.2.2.2 Brake Shoe and Wheel Wear

The TTC subway car fleet is composed of two basic car designs. They are described in more detail in Section 3.2. The older Gloucester ('G') cars are equipped with only a mechanical braking system in which composition brake shoes press against the wheels to decelerate the trains from operating speed to full stop. The newer Montreal and Hawker-Siddeley ('M' and 'H') type cars operate with a dual braking system. These trains decelerate from operating speed to about 8 kilometers per hour (5 mph) by means of an electrodynamic system. At this speed, a mechanical system similar to that on the 'G' cars is used to bring the train to a complete stop.

The friction materials used in the brake shoes must meet design criteria related to stopping ability, noise generation, wheel wear, and heat dissipation. Brake shoe life is also critical in that the friction materials are relatively soft and susceptible to heavy wear and, therefore, produce particulate emissions. The emission of some particulate matter from brake shoe materials in service is unavoidable according to current design practice. These particulate emissions will comprise small pieces of the brake shoes and, to a lesser extent, the wheels. Deceleration by the electrodynamic system does not involve application of the brakes (until 8 km/hr) and produces only those emissions discussed in 3.1.2.2.1, in addition to heat.

3.1.2.2.3 Tunnel Linings

All underground sections of the TTC subway system are lined or coated with sound absorption (acoustic attentuation) materials. The materials applied to the tunnel walls in parts of the University section and parts of the North Yonge extension contain some chrysotile asbestos fibre for flame retardation and physical strength. Since air velocity design criteria for the TTC subway allow for air speeds up to 610 m/min (22 miles per hour) at platforms and higher velocities in tunnels, it was thought that some of the lining might be dislodged into the airstream.

3.2 TTC Subway Operating Characteristics

Figure 3.1 graphically represents the current layout of the subway system and stations. Because the Spadina line opened in January 1978, most of the experimental program was performed on the Yonge-University section of the north-south system except for the April 1978 occupational survey (Section 5.3).

The subway train service schedule in Table 3.1 was current in July 1978 and is typical of the service. The major effect of the opening of the Spadina line in the context of the air quality survey is that, since the new trains used are 'H' type, the concentration of 'G' type cars in use has been diluted on the north/south lines.

Because of the different braking systems and the potential for emissions, the vehicle characteristics are important. Table 3.2 displays the characteristics of the 'G' and 'H' cars.

The Lawrence and Bay Stations were subjects of an extensive air quality investigation, and Tables 3.3 and 3.4 list the frequency with which subway cars passed by the air monitors at these stations. These data relate to the Yonge/University line before the Spadina line opened.

TABLE 3.1

SUBWAY TRAIN SERVICE SCHEDULE

July 1978

YONGE-UNIVERSITY-SPADINA		Headway (minutes)	Trains
Daily	6:00 - 7:00	3.42	29
	7:00 - 9:00	2.15	38
	9:00 - 16:00	3.42	29
	16:00 - 18:00	2.15	43
	18:00 - 22:00	3.42	29
	22:00 - 2:00	4.40	23
Saturday	7:00 - 18:00	3.42	29
	18:00 - 22:00	3.42	29
	22:00 - 2:00	4.40	23
Sunday & Holiday(s)	All Day	4.40	23

BLOOR-DANFORTH		Headway (minutes)	Trains
Daily	6:00 - 7:00	4.49	16
	7:00 - 9:00	2.55	27
	9:00 - 16:00	4.49	16
	16:00 - 18:00	2.55	27
	18:00 - 22:00	5.04	15
	22:00 - 2:00	5.04	15
Saturday	7:00 - 19:30	4.45	16
	19:30 - 22:00	4.45	16
	22:00 - 2:00	5.04	15
Sunday & Holiday(s)	All Day	5.04	15

TABLE 3.2

Vehicle Characteristics
December, 1979

CAR DATA	GLOUCESTER CARS (G)	HAWKER-SIDDELEY CARS (H)	MONTREAL CARS (M)
Peak-Period Train Length	8 cars	6 cars	6 cars
Car Weight	84,000 lbs.	55,500 lbs.	59,900 lbs.
Off-Peak Period Train	6 cars	4 cars	4 cars
Seating Capacity	62 people	83 people	84 people
Average Full-Load Capacity*	208 people	300 people	310 people
Weight Ratio: Full Load/ Empty*	1.37	1.81	1.78
Braking System	Mechanical	Mech/dynamic	Mech/dynamic
No. of Brake Shoes/Car	16	8	8
No. of Speed Setting**	1	2	2

* Average passenger weight 150 lbs.

** Speed Settings: 1 = maximum speed about 35 m.p.h.
2 = maximum speed about 45 m.p.h.

NOTE: TTC fleet of subway cars consists of:

'G' Type - 134
'M' Type - 36
'H' Type - 462

TABLE 3.3

Lawrence Station: Frequency of Operation in One Direction (Cars Passing/Hr)

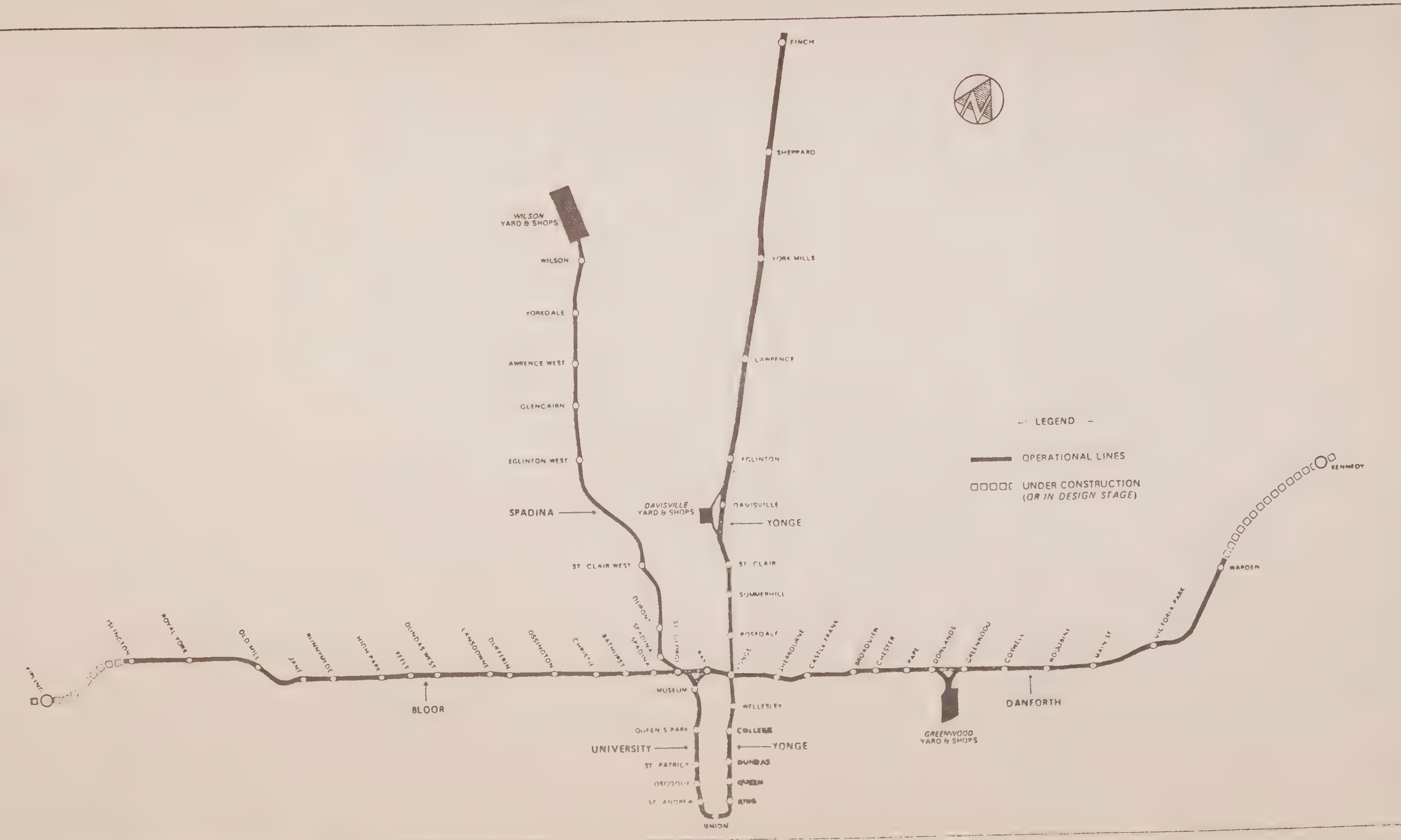
Date (1977)	0700-0900		0900-1600		1600-1800		1800-2200		2200-0200		AVG.	
	G	H	G	H	G	H	G	H	G	H	G	H
Apr. 21 (TH)	49.0	47.3	63.1	57.9	89.3	86.1	64.0	57.4	62.9	33.7	64.5	54.5
Apr. 22 (F)	49.0	47.3	70.2	52.6	89.3	86.1	70.2	52.6	80.9	20.2	72.2	48.8
Apr. 23 (SA)	84.2	42.1	84.2	42.1	84.2	42.1	84.2	42.1	84.2	42.1	85.4	36.1
Apr. 24 (SU)	-	-	107.8	-	107.8	-	107.8	-	107.8	-	107.8	-
Apr. 25 (M)	49.0	47.3	63.1	57.9	89.3	86.1	75.4	21.0	[illegible]	27.0	62.2	45.5
Apr. 26 (T)	49.0	47.3	63.1	57.9	95.6	81.3	65.9	14.0	53.9	18.0	57.9	41.6
Apr. 27 (W)	49.0	47.3	63.1	57.9	89.3	[illegible]	84.2	14.0	53.9	18.0	60.1	57.8
Apr. 28 (TH)	52.5	44.6	63.1	57.9	95.6	81.3	56.1	63.1	44.9	47.2	37.9	73.2
Apr. 29 (F)	49.0	47.3	42.1	73.7	89.3	86.1	29.1	84.2	[illegible]	68.0	63.1	52.8
Apr. 30 (SA)	63.3	57.9	63.1	57.9	63.2	57.9	63.2	57.9	62.9	33.7		
May 1 (S)	-	-	-	80.9	-	80.9	-	80.9	-	80.9	-	80.9
May 2 (M)	52.5	44.0	49.1	80.4	95.6	97.3	77.2	21.0	40.4	87.0	49.4	71.9
May 3 (T)	52.5	44.0	70.2	52.6	95.6	91.3	80.5	10.5	60.1	10.5	73.0	37.7
May 4 (W)	49.0	47.3	[illegible]	[illegible]	[illegible]	81.3	87.7	17.5	47.2	22.5	62.7	45.2
May 5 (TH)	49.0	47.3	63.1	57.9	95.6	81.3	70.2	52.6	[illegible]	[illegible]	70.3	50.2
May 6 (F)	52.5	44.6	63.1	57.9	95.6	81.3	63.1	57.9	71.9	27.0	67.3	52.4
May 7 (SA)	84.2	42.1	84.2	42.1	84.2	42.1	84.2	42.1	80.9	20.2	83.5	37.5
May 8 (S)	-	-	71.9	27.0	71.9	27.0	71.9	27.0	71.1	27.0	71.9	27.0
May 9 (M)	52.9	44.6	70.2	52.6	95.6	81.3	83.5	10.5	60.7	13.5	73.0	37.7

TABLE 3.4

Bay Station: Frequency of Operation in One Direction (Cars Passing/Hr)

Date (1977)	AM RUSH 0700-0900	DAY NORMAL 0900-1600	PM RUSH 1600-1800	EARLY EVG 1800-2200	LATE EVG 2200-0200	AVG.
Apr. 21 (TH)	148.14	80.17	148.14	71.42	47.61	85.78
Apr. 22 (F)	148.14	80.17	148.14	71.42	71.42	90.80
Apr. 23 (SA)	80.89	80.89	80.89	80.89	71.42	78.90
Apr. 24 (S)	-	47.61	47.61	47.61	47.61	47.61
Apr. 25 (M)	148.14	80.17	148.14	71.42	47.61	85.78
Apr. 26 (T)	148.14	80.17	148.14	71.42	47.61	85.78
Apr. 27 (W)	148.14	80.17	148.14	71.42	71.42	90.80
Apr. 28 (TH)	148.14	80.17	148.14	71.42	47.61	85.78
Apr. 29 (F)	148.14	80.17	148.14	71.42	47.61	85.78
Apr. 30 (SA)	80.89	80.89	80.89	80.89	71.42	78.90
May 1 (S)	-	47.61	47.61	47.61	47.61	47.61
May 2 (M)	148.14	80.17	148.14	71.42	47.61	85.78
May 3 (T)	148.14	80.17	148.14	71.42	47.61	85.78
May 4 (W)	148.14	80.17	148.14	71.42	47.61	85.78
May 5 (TH)	148.14	80.17	148.14	71.42	47.61	85.78
May 6 (F)	148.14	80.17	148.14	71.42	47.61	85.78
May 7 (SA)	80.89	80.89	80.89	80.89	71.42	78.90
May 8 (S)	-	47.61	47.61	47.61	47.61	47.61
May 9 (M)	148.14	80.17	148.14	71.42	47.61	85.78

FIGURE 3.1 MAP OF TTC SUBWAY SYSTEM



4.0 ENVIRONMENTAL TEST PROGRAM

4.1 October 1976 Survey

An intensive field survey took place in the TTC subway system during October 18-22, 1976. The objectives of the study were to determine concentrations of asbestos fibres, total suspended particulate (TSP), and the concentrations of various components of TSP. The sampling instruments were strategically positioned to identify the major sources of emissions to the subway air.

Asbestos sampling instruments were located in the tunnels near the platforms at the following stations: Lawrence, Sheppard, Bloor, College, St. Patrick, and Queen's Park on the Yonge-University line; Yonge and Woodbine on the Bloor-Danforth line. High-volume air sampling instruments with glass fibre filters were positioned beside the asbestos samplers at Lawrence, Woodbine, and College Stations. High-volume samplers for asbestos were located at the Ellis Portal (tunnel opening to open-air track) between Bloor and Rosedale Stations and near the tunnel opening at Eglinton Station. A size-fractionating particle counter, a size-fractionating high-volume air sampler, and a vapour-phase organic matter sampler were operated in the tunnel adjacent to Queen's Park Station.

Samples of airborne particulate matter were collected in the ventilation shaft to the street at Sheppard Station by means of a high-volume source-testing apparatus. A conventional high-volume ambient air sampler was operated in the vent shaft to the street (sidewalk) at College Station.

Airborne particulate matter samples were collected aboard trains running on both the Bloor-Danforth and Yonge-University lines with equipment similar to that used for trackside sampling.

Twenty-four personnel breathing-zone filter samples were collected from subway employees (in station, track, and train operation duty areas) and from "simulated passengers" (MOL technicians).

During this survey, about 90 filter samples were collected by various techniques for analysis of the following parameters: total mass concentration of airborne particulate matter, asbestos fibre count and mass concentrations, concentrations of heavy metals (elements), identification and approximate concentration of organic compounds adsorbed on the TSP, particle size distribution and metals analysis in five size-fractions. In addition, the two samples of organic vapours collected on adsorbent cartridges were analyzed qualitatively.

4.1.1 Analysis of Samples

All analyses for asbestos fibres were carried out by Ontario Research Foundation (ORF) according to established procedures.

Fifteen of the filters were examined by electron microprobe/x-ray fluorescence (XRF) by ORF to determine the qualitative elemental composition. Because of matrix effects, these XRF data provided only an approximate elemental analysis. Aliquots of Nuclepore filters were coated with carbon prior to subjecting them to the SEM beam; therefore, carbon analysis could not be achieved. This method, in addition, is not sensitive to elements of atomic number 10 or less.

Glass fibre filters exposed on high-volume samplers were divided for inorganic and organic analysis, respectively, between the MOE Air Quality Laboratory in Toronto and the University of Waterloo's Department of Chemistry. Inorganic analyses were carried out according to standard MOE techniques. Organic analyses were performed on methyl alcohol extracts of the exposed filters, comprising gas chromatographic (GC) separation and detection of the components of the extract without further sample work-up. The objective of the organic analysis was to compare the composition of the organic fraction of the subway TSP with that of TSP collected in typical ambient locations elsewhere in Ontario.

Mass concentrations of TSP on glass fibre filters were determined by the MOE Air Quality Laboratory.

The organic vapour samples were collected and analysed as follows: Two to three cubic meters of air were drawn through a prefilter and a cartridge containing a porous polymer-resin adsorbent (Tenax GC). The organic vapours adsorbed from the air stream onto the cartridge were eluted and subjected to various gas chromatography-liquid chromatography-mass spectrometry analyses. The only organic substances that appeared were the components of typical gasoline mixtures. No other organic compounds were found. The concentrations of organic compounds could not be determined because the large volumes of air sampled exceeded the break-through volumes for light hydrocarbons. This procedure, in other words was suitable for qualitative identification but not quantitative determination. This work was performed in the MOE Organic Trace Contaminants Laboratory.

4.1.2 Results:

Table 4.1 presents the results of analyses of 52 samples for asbestos fibre content. Each sample was collected over a period of three hours

except for those from high-volume samplers at portals or in ventilation shafts. Table 4.2 shows the TSP concentrations of six samples collected on high-volume samplers with glass fibre (GF) filters that were collected over periods of 18 to 24 hours. This table includes a mass determination for the individual size fractions of the Andersen cascade impactor high-volume sampler.

Multi-elemental analysis was performed on these filters as listed in Table 4.2 as well as on three polycarbonate filters exposed in the portals and vent shafts. Several filters exposed previously at streetside locations in Toronto were analysed for comparison. Several of the parameters could not be determined for some filters because of limiting physical or chemical properties of the filter material. These gaps are indicated by missing entries of Table 4.2.

A preliminary electron microprobe/x-ray fluorescence (XRF) analysis for selected elements was performed by Ontario Research Foundation on a selection of 15 of the Nuclepore membrane filters from the survey. This analysis of suspended particulate matter showed only iron of the elements heavier than sodium to be present in relatively large quantity in the TTC samples compared to the streetside samples. Iron comprised up to approximately 50 per cent of some samples.

Lead was not identified as a significant constituent of these TSP samples, but the sensitivity of the electron microprobe/XRF method for lead is quite low, that is, about a factor of 3 less than that for iron, calcium, or aluminum, for example.

The more sensitive MOE Laboratory method for lead (atomic absorption), however, identified this element as a significant component of the high-volume glass fibre filter samples. Lead comprised 2 to 4 per cent by mass of the particulate samples collected in the subway system during this survey.

The organic extracts of the glass fibre filters contained a relatively small amount of organic matter compared with typical, but heavily

loaded, ambient filters. The organic content of the TTC filters analyzed (six normal high-volume filters and one set of five Andersen sampler filters) contained no detectable heavy polycyclic hydrocarbons (more than four fused aromatic rings). Traces of aromatic hydrocarbons containing up to four condensed rings were found, but the qualitatively identified substances were straight-chain hydrocarbons and related compounds normally found on ambient airborne particulate matter. In summary, toxic organic substances appear to be present in subway TSP at concentrations no higher than would be found in ambient air TSP. This is as expected, since the only organic materials used in appreciable quantities in the subway system are lubricants, which are relatively inert hydrocarbon materials. Combustion or other high-energy chemical conversion processes do not take place in the subway system, and so production of toxic organics is not expected.

4.2 Follow-up Test Program

4.2.1 Introduction

Previous air quality surveys of the TTC subway system, as described above, had shown the air to contain elevated concentrations of suspended particulate matter relative to ambient air. The possible effect on the health of passengers in the subway system necessitated investigation into the cause and means of reducing these levels. Results of the October 1976 survey and analysis of typical brake shoes (Section 6.1.1.) suggested that subway car brake shoe wear was a main contributor to the particulate level, especially for the elements carbon (graphite), iron, and lead. The subsequent monitoring program included:

1) demonstrating the effect of wall washing at the Queen's Park and Lawrence Stations (February 8-22, 1977);

2) demonstrating the effect of different types of subway cars on the general air quality of the tunnels (April 21-May 10, 1977);

3) on-train air sampling to determine the air quality and public exposure inside the different subway trains (August 16-17,1977).

4.2.2 TTC Operational Parameters (see also Section 3)

Much of the MOE monitoring was based upon TTC operating schedules. TTC time intervals were categorized as follows:

0700-0900 (a.m. rush)
0900-1600 (day normal)
1600-1800 (p.m. rush)
1800-2200 (late evening)
0200-0600 (no service)

The Lawrence and Bay Stations were selected for monitoring as representative of the Yonge-University and Bloor-Danforth lines, respectively. The frequency of subway cars passing through Lawrence and Bay Stations was calculated for the April 21-May 10, 1977 study to determine the number and type of cars passing by the samplers and to allow for a more accurate interpretation of the monitoring data (presented in Tables 3.3 and 3.4).

Important during the evaluation of the effects of different types

of subway cars are their individual specifications, and these are given in Table 3.2. Subway cars built by Hawker-Siddeley and Montreal Locomotive Works operate on the entire system, while cars built by Gloucester Railway Carriage are restricted to the Yonge-University -Spadina line. The Montreal ('M') and Hawker-Siddeley ('H') cars are equipped with a dual braking system employing both electrodynamic (traction motor) and mechanical (friction) braking methods. The Gloucester ('G') cars are equipped only with mechanical brakes. It is also notable that the 'G' cars have twice as many brake shoes per car as the 'H' and 'M' cars, in part because of the much greater weight of the 'G' cars.

4.2.3 Air Monitoring Instrumentation

The air monitoring instruments used by the MOE in this survey were the standard high-volume (Hi-Vol) sampler, the Andersen cascade impactor size-fractionating attachment, and the continuous coefficient-of-haze (COH) monitor.

The Hi-Vol sampler is designed to draw a large volume of air (1500-2500 m^3 per 24 hours) through an 8" x 10" filter sheet. Under controlled humidity conditions, the filter is weighed before and after the sampling period to determine the mass of particles collected from the measured volume of air. Subsequent elemental analysis was performed by the MOE laboratory Services Branch. Sub-sections of the filters were analyzed for lead (Pb) and iron (Fe) by atomic absorption techniques and for free carbon (C) by combustion and analysis of the gas stream by thermal conductivity.

The Andersen cascade impactor size-fractionation head, comprising five filters in series, attaches to the normal Hi-Vol intake port. It separates the particles into size fractions with effective cut-off diameters of 7.0

um, 3.3 um, 2.0 um, and 1.1 um at a flowrate of 20 cubic feet of air per minute (cfm).

The COH monitor provides estimates of suspended particulate level on a continuous basis. The device operates by drawing air through part of a continuous strip of filter paper, entrapping particulate matter upon it. By comparing the amount of light passing through the exposed portion of the tape with that passing through the unexposed tape, it provides a measure of the concentration of suspended particulates in terms of "Coefficient of Haze" (COH)*. The amount of light from a calibrated source passing through the filter is detected by a photo-sensitive cell. The difference in signal caused by darkening of the filter tape produces an output which is proportional to the particle loading. Thus, COH values are obtained in terms of the amount of a recorder chart deflection, which is usually averaged over one-hour periods.

During the Queen's Park survey, the COH values were obtained over one-hour sampling times, but, because of the loading, the instrument response was non-linear, and only the first 15 minutes of a given chart were read. The values were then extrapolated to obtain the one-hour average COH. During the Lawrence/Bay survey the flow rate and time period were reduced by half (13.6 cfh for 30 minutes), and the chart deflections were again adjusted to give equivalent hourly values.

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* The coefficient of haze is a measure of visibility reduction in the atmosphere and is related to the concentration of TSP along the path of vision. One COH unit is defined as 100 times the optical density of the darkened spot on the filter tape. The COH is usually expressed on the basis of 1000 linear feet of air passing through the filter spot. This is determined from the ratio of the product of the volumetric flowrate and the duration of sampling to the area of the filter spot.

Although the COH value is unitless, it can be related to the concentration of the total suspended particulate (TSP). The TSP/COH relationship was investigated for the Lawrence, Bay, and Queen's Park Stations, and the results are presented in Appendix B. To compare with the Hi-Vol data, the hourly COH values were averaged over the same sampling period.

4.2.4 Survey design and Results

The survey was divided into 3 phases:

1) monitoring the effect of tunnel wall washing as a method of controlling the concentrations of suspended particulates during service.

2) monitoring TSP concentrations during periods of exclusive use of each of the two basic types of subway cars to try to determine the relative difference in braking emissions.

3) measuring passenger exposure by on-train sampling of suspended particles.

Figure 4.1 contains the physical layout details for each station.

4.2.4.1 Phase I: Wall Washing and Fan Tests

The survey at the Queen's Park Station, chosen by the TTC for measuring the effect of wall washing, was conducted from February 8 to February 22, 1977. A calibrated MOE COH sampler and a Hi-Vol sampler, located just off the south end of the passenger loading platform, were operated by TTC staff for 24 hours each day. The results were assessed and compared on the basis of the following:

1) peak COH value in the morning;

2) peak COH value in the afternoon;

3) average COH value from 0900 - 1600;

4) average COH value from 1800 - 2200.

These COH values were compared with the number of wall washings performed the night before (0, 1, 3, or 6). The wall-wash test section was from the south end of the Museum Station to the south end of St. Patrick Station, a distance of 2.7 km (north and southbound tunnels washed).

The morning and afternoon peak and average COH values are summarized in Table 4.3. Two COH peaks were observed each day around 0800 and 1700 during the interval when the subway was operating at a rate of one train every two minutes.

The average of the morning peak COH values following the days without wall washing (February 9, 11, 14, 18, 21, and 22, 1977) was 18; the peak values for February 10, 15, and 16, 1977 averaged 17 after 1, 3, and 6 wall washings, respectively, had been performed the night before. These data would indicate that this 7 per cent decrease in COH may be due to the effect of wall washing.

In the analysis of afternoon peak values, the average of the maximum COH values following days without wall washing was 17. The average for the days following one wall washing and three wall washings was 16, which corresponds to an 8 per cent decrease in COH.

The average COH value from 0900 to 1600 on days following no wall washing was 13; the average value for both one and three wall washings was 12. This is a 7 per cent decrease in COH. The Yonge-University line was operating at a rate of one train every 3.4 minutes during this period.

Evening COH values (1800 - 2200) averaged 12 for the days following no wall washing and 10 for both one and three washings, which corresponds to a 15 per cent decrease in COH. During the evening schedule the subway is operating at a rate of one train every 4.5 minutes. Efforts were made to correlate the number of wall washes and average COH values but there were not enough data to support any significant relation.

On March 14, one wall wash (both directions) was performed at Lawrence Station, but only a 5 per cent reduction in COH was measured.

At both Queen's Park and Lawrence Stations, the ventilation fans were operated for 24-hour test periods, but no significant reductions in COH values were observed.

4.2.4.2 Phase 2: Tests of 'G' only and 'M/H' only Trains

In the second phase of the survey (April 19-May 10, 1977) a COH sampler and a Hi-Vol sampler were set up just off the platform in the Lawrence Station on the Yonge-University line and in the Bay Station of the Bloor-Danforth line. On the Yonge-University line, the usual schedule of 'H', 'M', and 'G' trains was run. A special schedule was devised for Sunday, April 24, 1977 when only 'G' trains operated (12 trains of eight cars each) and on Sunday, May 1, 1977 when only 'H' and 'M' trains operated (12 trains of six cars). On May 8, a regular Sunday schedule of eight 'G' trains and four 'H' trains was run. In addition to the special test, the air was monitored throughout the week to obtain comparative results. Data were also obtained from the Bay Station over the same period for comparison with Lawrence Station data.

Hourly COH values were calculated as described above, and test period averages were calculated using TTC operation-schedule time intervals. Tables 4.6 and 4.7 list the COH values obtained at the Lawrence and Bay Stations, respectively.

The results of the 'G' and 'H' tests conducted at Lawrence Station on April 24, May 1, and May 8, 1977 (Sundays) are summarized in Table 4.5. The average COH when only 'G' cars were in service was 17, while the 'H' car tests averaged 8. A regular schedule of two-thirds 'G' cars and one-third 'H' cars averaged 13. Exclusive service of 'G' trains, therefore, produced a 30 per cent increase in COH above that measured during the regular Sunday schedule, while the

'H' train tests showed a 39 per cent decrease compared with the regular Sunday schedule. The average COH sampled during the 'G' car test was more than twice that for the 'H' car test.

The relationship between the frequency of 'H' and 'G' cars passing Lawrence and Bay Stations and the COH value was investigated. It is graphed in Figure 4.2. Appendix C presents the background data and analysis for this relationship.

A comparison of average weekday COH values for Lawrence and Bay Stations is presented in Table 4.8. The Hi-Vol data obtained during the survey, including the percentages of iron, carbon, and lead in the samples, are listed for Lawrence and Bay Stations in Tables 4.9 and 4.10.

4.2.4.3 Phase 3: On-Train Sampling Tests

The objective of the third phase (August 16-17, 1977) was to determine the particulate concentrations aboard 'H' and 'G' subway cars in service. Two Hi-Vol samplers were operated side-by-side in the centre car of an 'H' train in the morning and a 'G' train in the afternoon. Figure 4.3 depicts the arrangement of the equipment. One Hi-Vol sampler was used to obtain TSP concentrations; the other was fitted with an Andersen sampling head to separate the particles into size fractions. Each sampling run consisted of two round trips on the Yonge-University line (approximately two hours) with the ventilation dampers open on the 'H' cars and the windows open on the 'G' cars to achieve similar operating conditions. The results of the Andersen and Hi-Vol sampling are listed in Table 4.11.

TABLE 4.1

TTC AIR QUALITY SURVEY ASBESTOS ANALYSIS RESULTS

MOE CODE	LOCATION	Date	Time	Concentration of Chrysotile Asbestos [a,b,c]		
				f/ml		ug/m3 (all fibre lengths)
				Total	>5um in length	
TRACKSIDE	SURVEY					
29	Woodbine Station	19/10/76	0745-1145	0.05	0.02	0.003
32	College Station	19/10/76	0755-1100	0.7	BDL(0.03)	0.4
27	Lawrence Station	19/10/76	0812-1125	2.0	0.3	0.04
31	Queen's Park Station	19/10/76	0815-1112	1.3	0.03	20
30	St. Patrick Station	19/10/76	0810-1105	1.3	0.03	0.01
28	Sheppard Station	19/10/76	0800-1100	0.8	0.06	0.8
25	Yonge Station	19/10/76	0800-1100	0.2	BDL(0.05)	0.001
26	Bloor Station	19/10/76	0800-1100	0.3	BDL(0.03)	0.002
33	Queen's Park Station	19/10/76	1112-1415	1.5	0.2	0.09
34	Sheppard Station	19/10/76	1109-1404	0.4	BDL(0.05)	0.007
35	Lawrence Station	19/10/76	1125-1425	0.5	0.15	0.3
36	Woodbine Station	19/10/76	1115-1412	.07	0.01*	0.2*
37	College Station	19/10/76	1100-1415	0.3	0.04*	0.6*
38	Yonge Station	19/10/76	1100-1415	0.2	BDL(0.03)	0.04*
39	Bloor Station	19/10/76	1100-1415	0.2	0.02	0.001
40	St. Patrick Station	19/10/76	1105-1400	0.4	0.07*	0.1
41	Lawrence Station	20/10/76	0800-1055	0.8	0.07	0.4
42	Sheppard Station	20/10/76	0816-1111	1.0	0.15	0.3
43	Woodbine Station	20/10/76	0800-1105	.04	BDL(0.01)	0.0005
45	Lawrence Station	20/10/76	0300-0600	.09	BDL(0.005)	0.001
46	Bloor Station	20/10/76	0740-1050	0.3	BDL(0.03)	0.03
47	Yonge Station	20/10/76	0735-1050	.06	BDL(0.03)	0.005
48	Queen's Park Station	20/10/76	0810-1104	0.3	BDL(0.06)	0.004
49	St. Patrick Station	20/10/76	0805-1057	2.4	0.3	0.02
50	College Station	20/10/76	0755-1100	.2	BDL(0.03)	0.0006
51	Lawrence Station	20/10/76	1100-1400	.4	BDL(0.06)	0.03
52	Sheppard Station	20/10/76	1111-1412	0.8	0.1	2.5
53	Yonge Station	20/10/76	1040-1350	.1	BDL(0.03)	0.008
54	Bloor Station	20/10/76	1050-1350	.07	BDL(0.02)	0.0004
55	College Station	20/10/76	1055-1355	.1	BDL (0.02)	0.002
56	Queen's Park Station	20/10/76	1110-1410	.5	0.07	0.03
57	St. Patrick Station	20/10/76	1120-1420	.4	BDL(0.06)	0.001

TABLE 4.1 (continued)

TTC Air Quality Survey Asbestos Analysis Results

MOE CODE	LOCATION	DATE	TIME	CONCENTRATION OF CHRYSOTILE ASBESTOS a,b,c		
				f/ml		ug/m3 (all fibre lengths)
				Total	>5 um length	
58	Woodbine Station	20/10/76	1116-1405	.3	BDL(0.02)	0.001
61	Lawrence Station	21/10/76	0200-0500	1.3	BDL(0.01)	0.2
62	Queen's Park Station	21/10/76	0200-0500	0.02	0.005	0.02
PORTALS AND STATION VENTS:						
9N	Ellis Portal	19/10/76	0800-1400	.02	BDL(0.002)	0.006
10N	Eglinton Portal	19/10/76	0800-1400	.5	BDL(0.02)	0.06*
11N	College Station Vent	19/10/76	0800-1400	0.08	BDL(0.004)	0.002
68N	Sheppard Station Vent -Net Flow from Tunnel to Ambient Air	19/10/76	Non-Rush Hour (4 hours intermittent)	0.4	BDL(0.02)	0.02
69N	Sheppard Station Vent -Net Flow Ambient Air into Tunnel	20/10/76	Non-Rush Hour (4 hours intermittent)	0.2	BDL(0.01)	0.04
70N	Sheppard Station Vent -Net Flow Ambient Air into Tunnel	20/10/76	1500-1800 (Rush Hour)	.08	BDL(0.03)	0.006
12N	Ellis Portal	20/10/76	0800-1400	.02	BDL(0.002)	.009*
14N	Eglinton Portal	20/10/76	0815-1415	.6	0.03	.330
13N	College Vent	20/10/76	0750-1350	.08	BDL(0.02)	.002
ON-TRAIN SAMPLES:						
15M	Yonge-University Line	19/10/76	1036-1252	2.7	BDL(0.2)	.041
22N	Yonge-University Line	19/10/76	1030-1252	.7	BDL(0.06)	.290
23N	Yonge-University Line	19/10/76	1030-1252	.9	0.08	.360
17M	Yonge-University Line	19/10/76	1300-1454	1.3	BDL(0.09)	.090
20N	Yonge-University Line	19/10/76	1300-1457	0.4	BDL(0.03)	.003
24N	Yonge-University Line	19/10/76	1300-1454	1.4	0.1	1.3
16M	Bloor-Danforth Line	20/10/76	1015-1245	.7	0.07	.012
21N	Bloor-Danforth Line	20/10/76	1015-1245	0.1	BDL(0.01)	.003

BDL = Below Detectable Limits
( ) = Detectable limit for that Sample
* = Denotes some Amphibole Fibres Counted in Sample

a) Environmental Guideline: 0.04 f/ml (>5 um)/24 hours

b) Environmental Guideline: 5.0 ug/m3/30 minutes

c) Occupational Standard: 2 f/ml (>5 um) time weighted average over 8 hrs.

TABLE 4.2

Air Quality Analytical Report: TTC Survey

Filter Number	Filter Type	Exposure Date 1976	Location	Air Volume m^3	Ca	Sn	Cr	Cu	Pb	Mn	Zn	Mg	Al	Fe	Ni	SiO_2	TSP
					Pollutants $\mu g/m^3$												
1GF	Glass Fibre	19 Oct.	Lawrence	883.43	56.43	0.08	1.711	6.60	93.7	10.47	2.3	23.63	22.21	1329.8	1.222	-	2503.
2GF	GF	19 Oct.	Woodbine	982.1	47.10	0.014	0.073	0.75	3.1	0.57	0.1	N.D.	N.D.	61.9	N.D.	-	148.
3GF	GF	19 Oct.	College	866.6	70.00	0.074	0.976	1.95	43.2	4.74	1.1	9.35	3.95	560.8	0.499	-	1018.
4GF	GF	20 Oct.	Lawrence	963.4	59.23	0.187	1.700	5.68	87.8	10.01	2.1	20.74	31.57	1214.4	1.121	-	2267.
5GF	GF	20 Oct.	Woodbine	1019.5	24.19	0.027	0.159	1.77	7.0	1.18	0.2	0.71	N.D.	147.9	0.088	-	305.
6GF	GF	20 Oct.	College	866.6	54.42	0.066	0.914	1.97	43.0	5.05	1.2	8.31	14.33	581.6	0.005	-	1126.
11N	Nuclepore	19 Oct.	College Vent	672.9	1.19	0.009	0.083	0.62	10.2	0.96	0.5	2.41	1.62	115.5	0.104	9.66	-
68N	Nuclepore	19 Oct.	Sheppard Vent - out	71.3	9.22	0.084	0.392	4.51	62.8	6.28	1.6	15.90	10.60	785.0	N.D.	65.88	-
69N	Nuclepore	20 Oct.	Sheppard Vent - in	69.4	2.05	0.043	N.D.	0.5	15.5	0.85	N.D.	3.57	1.02	120.9	N.D.	50.43	-
5.3.TW. 14.1.	Nuclepore	17 June	York St. Ramp	192.7	4.07	0.005	N.D.	0.15	2.5	N.D.	N.D.	1.84	0.65	2.8	N.D.	101.64	-
5.3.TW. 15.1.	Nuclepore	18 June	Don Mills/ Eglinton	170.8	3.44	N.D.	N.D.	N.D.	2.5	N.D.	N.D.	1.48	0.90	2.7	N.D.	125.90	-
Particle Size Fraction																	
≥ 7 um	Andersen	19 Oct.	Queen's Park	987.7	-	0.016	0.018	0.27	7.8	0.86	11.4	-	-	146.8	0.071	-	256.
3.3-7um	Andersen	19 Oct.	Queen's Park	987.7	-	0.018	0.140	0.38	10.6	1.22	10.3	-	-	165.0	0.093	-	262.
2.0-3.3 um	Andersen	19 Oct.	Queen's Park	987.7	-	0.013	N.D.	0.24	7.4	0.58	12.0	-	-	104.3	N.D.	-	163.
1.1.-2 um	Andersen	19 Oct.	Queen's Park	987.7	-	0.001	N.D.	0.18	3.6	0.35	11.6	-	-	49.6	0.012	-	80.
≤ 1.1um	Andersen	19 Oct.	Queen's Park	987.7	-	N.D.	0.054	0.30	3.6	0.28	0.2	-	-	36.5	N.D.	-	96.
														Total All Sizes			857.
≥ 7 um	Andersen	20 Oct.	Queen's Park	757.6	-	N.D.	0.04	0.33	8.7	1.06	13.9	-	-	138.6	0.23	-	276.
3.3-7um	Andersen	20 Oct.	Queen's Park	757.6	-	0.004	0.103	0.43	13.3	13.4	13.4	-	-	170.3	0.174	-	361.
2.0-3.3 um	Andersen	20 Oct.	Queen's Park	757.6	-	0.013	N.D.	0.27	7.3	0.66	15.3	-	-	85.8	0.044	-	168.
1.1 -2 um	Andersen	20 Oct.	Queen's Park	757.6	-	0.005	N.D.	0.22	4.3	0.40	12.0	-	-	50.2	0.024	-	129.
≤ 1.1um	Andersen	20 Oct.	Queen's Park	757.6	-	0.004	N.D.	0.29	4.2	0.33	0.3	-	-	22.4	0.013	-	113.
														Total All Sizes			1047

TABLE 4.3

COH Values before and after Wall Washing

Date 1977	Morning Peak COH Value		Afternoon Peak COH Value		Average COH Between 0900 - 1600	Average COH Between 1800 - 2200	COMMENTS
	Time	COH	Time	COH			
Feb. 9 (Wed.)	0800	20.4	1700	17.8	14.1	13.1	Day Before 1 Wall Washing Had Taken Place
Feb. 10[a] (Thurs.)	0800	18.7	1700	15.8	13.1	9.3	Just After 1 Wall Washing
Feb. 11 (Fri.)	0800	19.5	1700	17.8	15.2	12.1	1 Day After 1 Wall Washing Had Taken Place
Feb. 14 (Mon.)	0800	19.6	1700	16.2	13.43	11.2	Day Before 3 Wall Washings Had Taken Place
Feb. 15[b] (Tues.)	0800	15.3	1700	15.6	11.6	11.0	Just After 3 Wall Washings
Feb. 16[c] (Wed.)	0900	16.5	-	-	-	-	Just After 6 Wall Washings Had Taken Place (Recorder Shut Off Accidentally)
Feb. 17 (Thurs.)	-	-	1700	16.2	-	11.8	No Wall Washing
Feb. 18 (Fri.)	0900	17.1	1600	17.5	12.9	11.7	No Wall Washing
Feb. 21 (Mon.)	0730	14.9	1700	16.5	11.3	12.3	No Wall Washing
Feb. 22 (Tues.)	0800	16.9	-	-	-	-	No Wall Washing

a-Day After 1 Wall Washing b-Day After 3 Wall Washings c-Day After 6 Wall Washings

TABLE 4.4

COMPARISON OF COH VALUES FOR WALLWASHING EXPERIMENTS AT QUEEN'S PARK STATION

	AVG. PEAK VALUES		AVERAGE VALUES	
	MORNING	AFTERNOON	0900-1600	1800-2200
	COH	COH	COH	COH
NO WALL WASHING (Feb. 9,11,14,17,18,21,22)	18.1	17.0	13.4	12.0
WALL WASHING (Feb. 10,15,16)	16.8	15.7	12.4	10.2
PERCENTAGE DIFFERENCE	-7.2%	-7.6%	-7.5%	-15.0%

TABLE 4.5

SUNDAY 'H' and 'G' CAR TESTS AT LAWRENCE STATION

DATE	TIME PERIOD	TYPE OF TEST	AVERAGE COH	% DIFFERENCE RELATIVE TO REGULAR SUNDAY	% DIFFERENCE RELATIVE TO 'H' CAR TEST
April 24 (Sunday)	1000-2400	'G' Car Test	16.71	+30%	+113%
May 1 (Sunday)	1000-2400	'H' Car Test	7.86	-39%	0%
May 8 (Sunday)	1000-2400	Regular Sunday Schedule	12.82	0%	+63%

TABLE 4.6

DAYTIME AVERAGE COH: LAWRENCE STATION

Date	AM RUSH 0700-0900	DAY-NORMAL 0900-1600	PM RUSH 1600-1800	EARLY EVE 1800-2200	LATE EVE 2200-0200	TOTAL AVG
Thur.Apr.21						
Fri. Apr.22	12.2	13.3	14.2	15.2	13.7	13.8
Sat. Apr.23	15.9	15.5	16.4	15.4	15.6	15.6
Sun. Apr.24	-	15.9	16.7	17.2	16.7	16.5
Mon. Apr.25	15.1	14.9	15.6	15.1	13.8	14.8
Tues.Apr.26	14.0	17.2	19.3	17.1	15.4	16.7
Wed. Apr.27	16.2	16.1	18.4	16.5	15.8	16.4
Thurs.Apr.28	16.7	16.9	17.0	17.3	15.9	16.8
Fri. Apr.29	16.2	15.0	N.A.	N.A.	N.A.	-
Sat. Apr.30	N.A.	N.A.	N.A.	N.A.	N.A.	-
Sun. May 1	-	8.0	7.7	7.9	7.6	7.8
Mon. May 2	13.3	15.3	15.9	15.5	15.0	15.1
Tue. May 3	14.1	16.1	17.1	15.6	13.9	15.4
Wed. May 4	14.1	13.9	14.4	13.8	12.0	13.5
Thurs.May 5	10.9	12.9	13.7	13.0	12.1	12.6
Fri. May 6	15.2	15.4	17.7	16.2	14.4	15.6
Sat. May 7	13.9	16.4	18.3	17.7	15.7	16.4
Sun. May 8	-	13.7	13.1	13.5	14.8	13.9
Mon. May 9	15.2	15.3	16.0	15.5	14.8	15.3

TABLE 4.7

DAYTIME AVERAGE COH: BAY STATION

Date 1977	AM RUSH 0700-0900	DAY-NORMAL 0900-1600	PM RUSH 1600-1800	EARLY EVG. 1800-2200	LATE EVG 2200-0200	TOTAL AVG.
Tues.Apr.19	13.2	11.5	13.5	11.1	9.6	11.4
Wed.Apr.20	13.4	12.7	13.4	11.3	9.8	11.9
Thur.Apr.21	13.0	11.7	13.1	10.3	9.7	11.4
Fri. Apr.22	12.6	11.0	12.2	10.4	9.3	10.8
Sat. Apr.23	10.7	10.1	10.4	10.8	9.5	10.2
Sun. Apr.24	-	7.0	6.9	6.5	6.3	6.7
Mon. Apr.25	12.0	11.5	12.5	11.2	9.3	11.0
Tues.Apr.26	12.8	11.7	12.5	10.6	9.5	11.2
Wed. Apr.27	12.8	11.3	11.7	10.5	8.9	10.8
Thurs.Apr.28	10.7	9.1	10.7	8.9	9.1	9.4
Fri. Apr.29	12.3	10.0	10.3	8.9	9.6	10.0
Sat. Apr.30						
Sun. May 1						
Mon. May 2						
Tues May 3	10.8	11.7	13.1	11.0	9.2	11.1
Wed. May 4	12.9	10.7	12.4	10.5	8.6	10.6
Thurs.May 5	11.9	11.1	12.2	11.2	9.6	11.0
Fri. May 6	11.6	10.3	10.1	8.1	7.5	9.3
Sat. May 7	10.9	10.3	8.3	8.6	10.1	9.7
Sun. May 8	-	6.2	4.7	4.6	5.0	5.4
Mon. May 9	10.8	8.8	10.3	8.5	7.0	8.7

TABLE 4.8

AVERAGE DAY AND NIGHT (NO SERVICE) COH

Date	Lawrence Station		Bay Station	
	Average Weekday COH	Average COH (0200-0600)	Average Weekday COH	Average COH (0200-0600)
April 14			11.4	2.6
April 20			11.9	
April 21			11.4	2.5
April 22	13.8	2.4	10.8	2.1
April 23		3.0		1.9
April 24		2.7		1.8
April 25	14.8	1.6	11.0	1.4
April 26	16.7	2.9	11.2	
April 27	16.4	2.3	10.8	
April 28	16.8	2.9	9.4	
April 29			10.0	
April 30				
May 1				
May 2	15.1	2.2		
May 3	15.4	1.4	11.1	1.6
May 4	13.5	1.1	10.6	2.3
May 5	12.6	1.9	11.0	
May 6	15.6		9.3	
May 7		2.5		1.8
May 8		2.6		1.5
May 9	15.3	1.8	8.7	2.3
May 10				1.5
Average	15.1	2.2	10.6	1.9

TABLE 4.9

HI-VOL RESULTS FOR LAWRENCE STATION

Filter Number	Exposure Date 1977	Air Flow m^3	Particulate Loading mg	T.S.P. ug/m^3	% Fe in T.S.P.	% C in T.S.P.	Pb ug/m^3
33021 019	April 20-21	1585	2537	1601	54.9	9.2	57.4
44031 101	April 21-22	1699	2640	1554	57.7	8.7	60.5
44031 102	April 24-25	1347	2499	1855	45.9	6.1	63.1
33029 124	April 25-26	1531	2305	1505	62.0	5.5	54.8
33029 125	April 26-27	1473	2587	1756	42.6	6.5	49.7
33029 127	April 27-28	1503	2789	1855	53.4	8.2	64.4
44031 095	March 15-16	1541	2146	1392	55.7	9.2	51.3
35038 050	March 14-15	1541	2106	1366	53.9	5.0	52.9
35038 049	March 13-14	1546	1908	1234	34.1	7.8	30.6
35038 048	March 10-11	1509	2472	1638	47.2	9.8	57.9
35038 047	March 9-10	1529	2142	1401	52.4	9.7	55.6
35038 046	March 8-9	1539	1223	795	62.2	11.9	32.2
33029 140	May 4-5	1706	2247	1317	46.9	7.8	42.2
33029 138	May 3-4	1590	2089	1314	36.7	7.6	32.7
33029 136	May 2-3	1601	2671	1669	38.8	6.3	45.0
33029 133	May 1-2	1955	1459	746	56.8	7.7	24.8
33029 131	April 28-29	1600	2630	1643	61.5	7.9	63.5
33029 129	April 28	243	520	2139	61.1	8.2	87.5
Weekday	Mean			16[illegible]5.4	51.6	7.6	55.8
Weekday	Std. Deviation			246.5	9.64	1.15	15.04

TABLE 4.10

HI-VOL RESULTS FOR BAY STATION

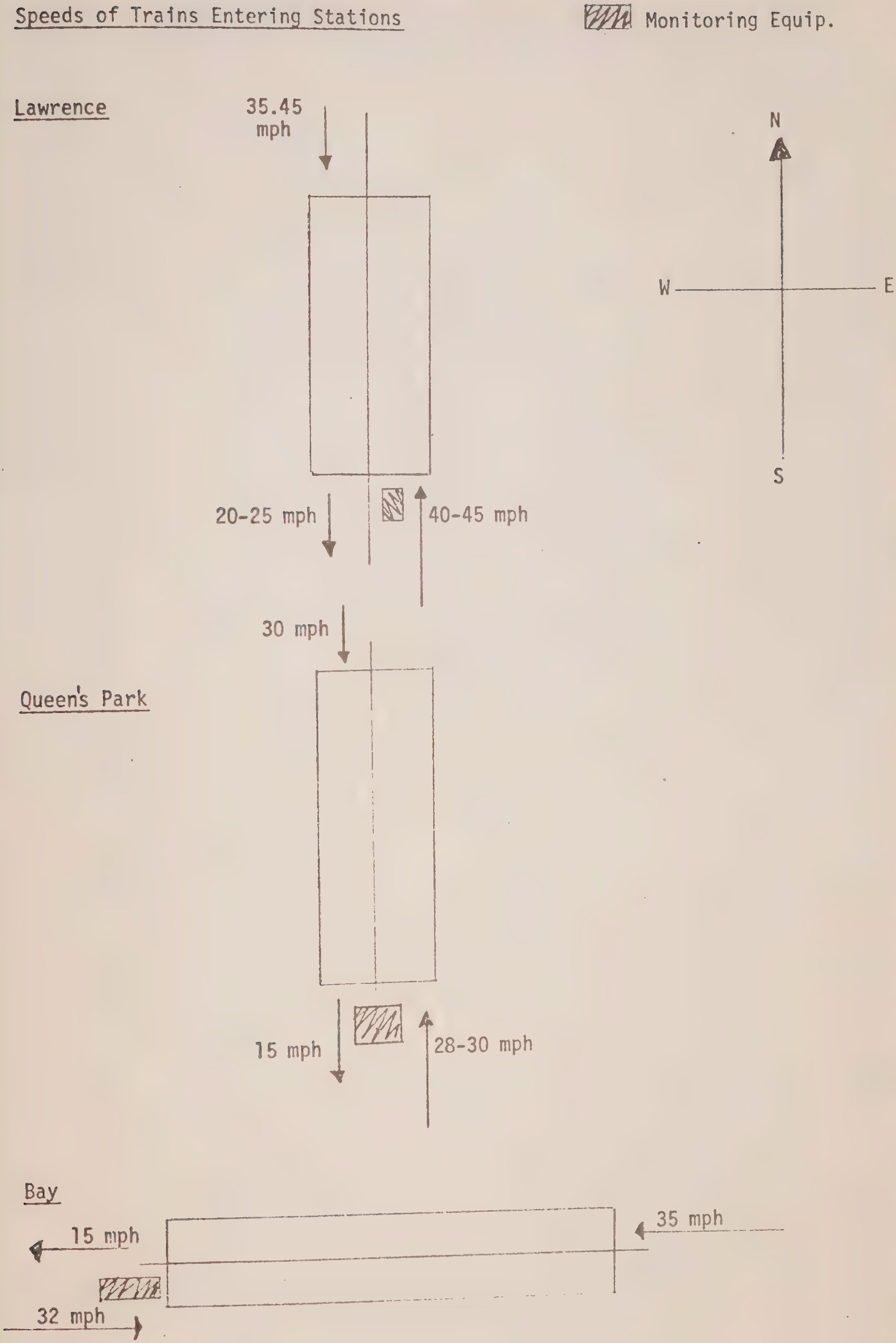
Filter Number	Exposure Date 1977	Air Flow m^3	Particulate Loading mg	T.S.P. ug/m^3	% Fe in T.S.P.	% C in T.S.P.	Pb ug/m^3
44031 097	April 18-19	I N V A L I D					
44031 098	April 19-20	1642	1104	672	51.3	7.5	17.3
44031 099	April 20-21	1609	1137	707	53.6	9.3	17.6
44031 100	April 21-22	1641	1095	667	53.0	8.4	17.3
33029 139	May 4-5	1575	911	578	52.8	11.1	14.2
33029 126	April 26-27	1644	1044	635	54.1	9.5	17.3
33029 128	April 27-28	1676	1004	599	52.2	9.6	14.1
33029 130	April 28-29	1668	956	573	52.8	10.7	14.2
33029 135	May 2-3	1662	900	541	56.1	9.4	12.8
33029 137	May 3-4	1650	1061	643	53.3	10.4	17.9
Weekday	Mean			623.9	53.2	9.5	15.9
Weekday	Std. Deviation			54.5	1.34	1.12	1.98

TABLE 4.11

ON-TRAIN TESTING: ANDERSEN AND TSP RESULTS

TEST TYPE	DATE EXPOSED	SIZE FRACTION	PARTICULATE LOADING mg	T.S.P. $\mu g/m^3$	CU		Pb		Fe		
					wt %	$\mu g/m^3$	wt %	$\mu g/m^3$	wt % Fe	wt % FE_3O_4	$\mu g/m^3$
'G' Car Test Andersen Head	Aug. 16	7.0	39.1	401	.17	.67	4.2	16.7	67	92	267
	Aug. 16	3.3	50.0	513	.15	.78	4.3	21.9	58	80	296
	Aug. 16	2.0	24.6	253	.17	.44	4.3	10.8	59	82	149
	Aug. 16	1.1	5.0	51	.71	.36	12.7	6.5	71	98	36
	Aug. 16	<1.1	7.3	75	.44	.33	3.9	2.9	39	53	29
TOTALS				1293	.20	2.58	4.5	58.8	60	83	777
'H' Car Test Andersen Head	Aug. 17	7.0	9.5	139	.15	.21	3.5	4.9	60	84	84
	Aug. 17	3.3	19.7	288	.15	.42	3.7	10.6	59	82	170
	Aug. 17	2.0	10.3	151	.18	.27	4.6	6.9	68	94	103
	Aug. 17	1.1	7.4	108	.28	.30	4.6	5.0	63	87	68
	Aug. 17	<1.1	6.7	98	.34	.33	4.6	4.5	32	44	31
TOTALS				784	.20	1.53	4.1	31.9	58	80	456
'G' Car Test Andersen Head	Aug. 17	7.0	21.0	307	.15	.47	4.4	13.4	65	90	199
	Aug. 17	3.3	25.1	367	.16	.57	4.6	16.9	62	86	228
	Aug. 17	2.0	10.1	148	.21	.31	5.8	8.6	60	83	89
	Aug. 17	1.1	8.6	126	.25	.31	5.6	7.0	66	91	83
	Aug. 17	<1.1	9.2	135	.30	.41	4.2	5.7	29	40	39
TOTALS				1083	.19	2.07	4.8	51.6	50	69	638
'G' Car Test Hi-Vol	Aug. 17	ALL	189.4	1274	.22	2.83	4.1	51.8	52	73	668
'G' Car Test Hi-Vol	Aug. 16	ALL	363.7	1287	.21	2.75	3.8	49.5	52	72	674
'H' Car Test Hi-Vol	Aug. 17	ALL	158.6	848	.28	2.39	3.4	28.5	49	67	412

FIGURE 4.1



06/06/77

FIGURE 4.2

Average Hourly COH vs. Frequency of Operation for Operation of Only One Type of Train on the Line

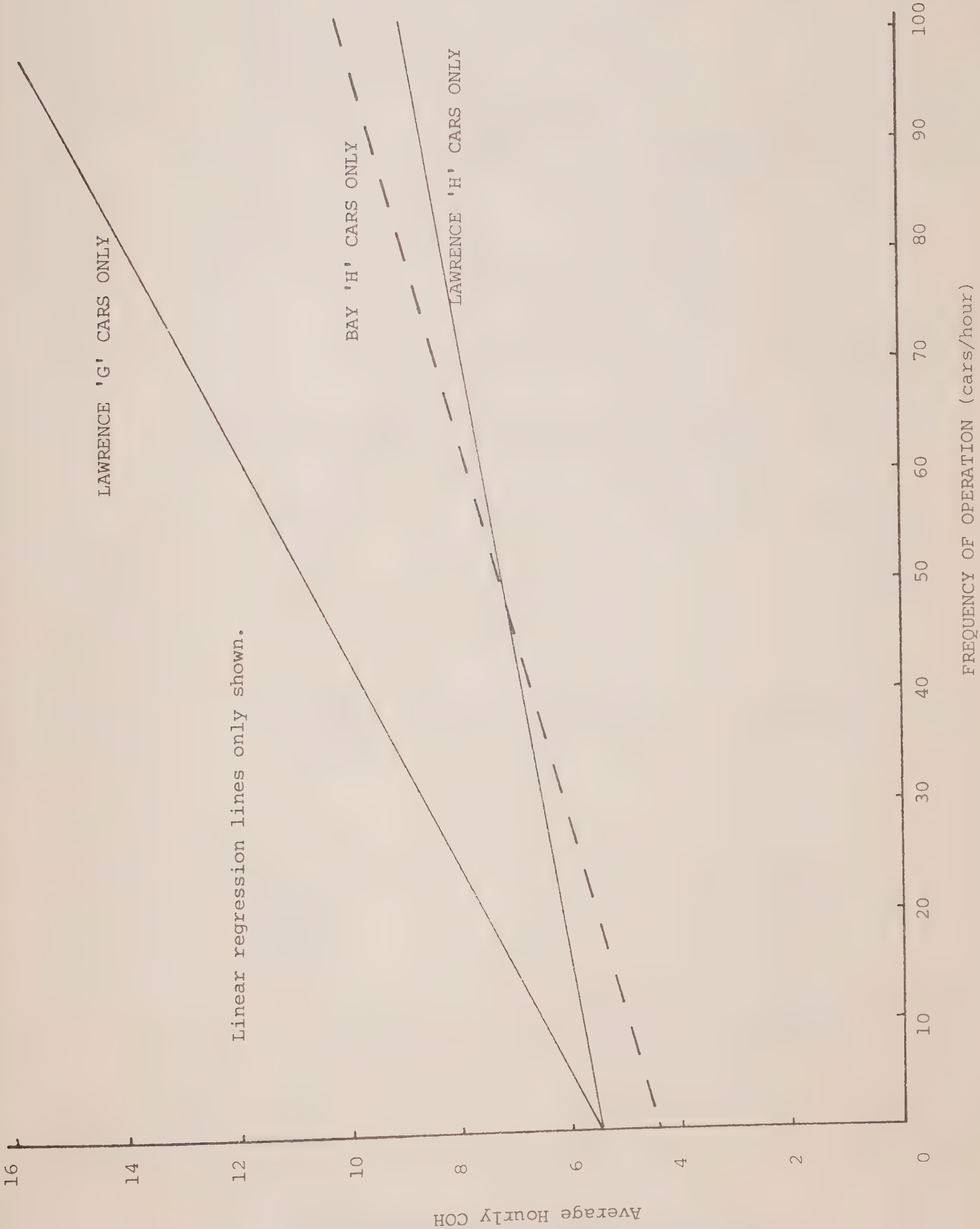
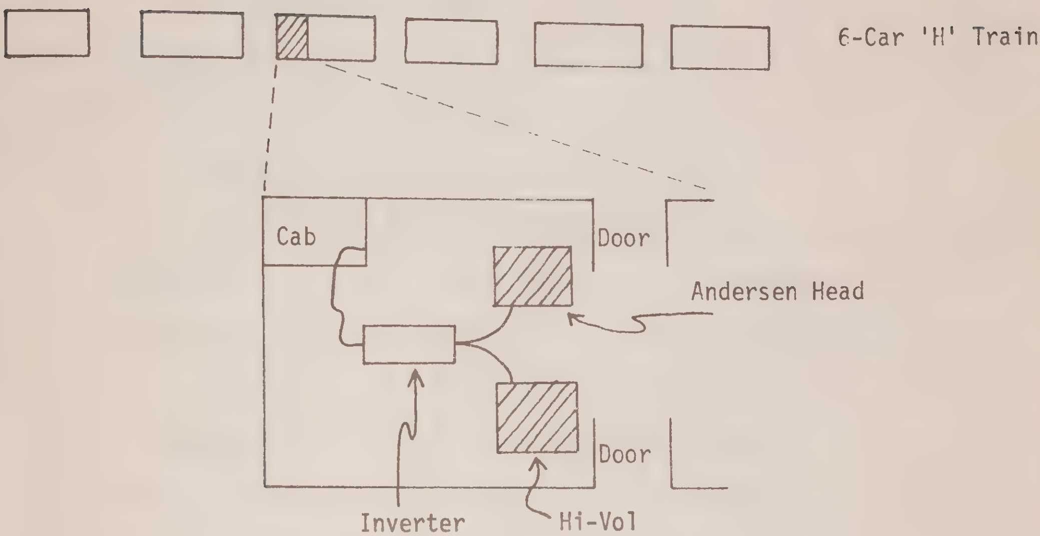
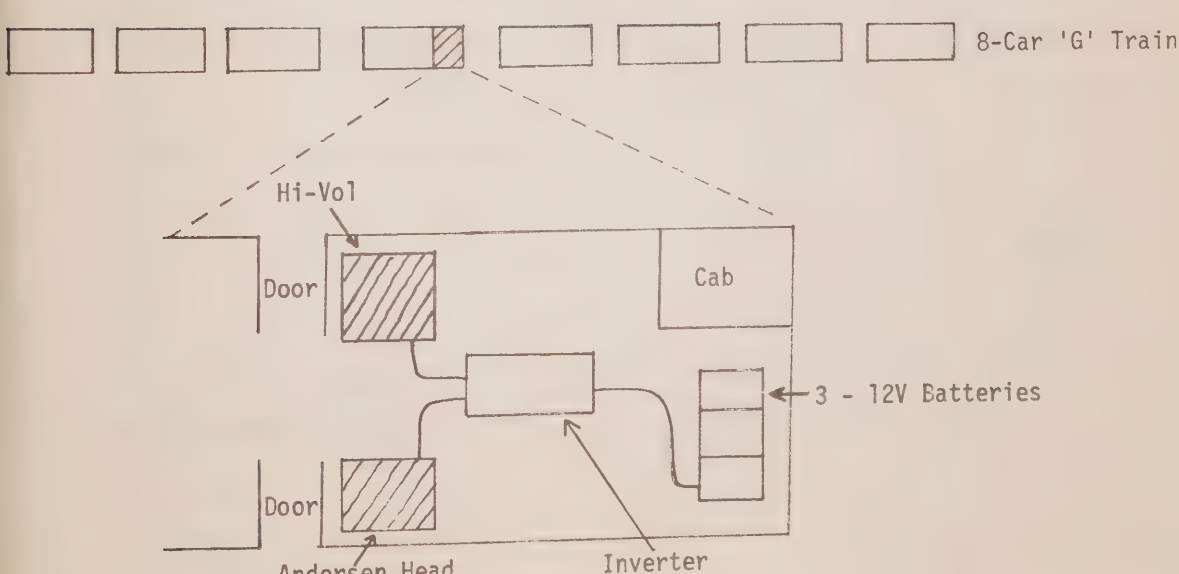


FIGURE 4.3

PLACEMENT OF ON-TRAIN SAMPLING EQUIPMENT



Placement of Survey Equipment on 'H' Test



Placement of Survey Equipment On 'G' Test

5.0 OCCUPATIONAL HEALTH TEST PROGRAM

5.1 October 1976 Survey

Twenty-four personnel breathing zone filter samples were collected from TTC employees working on both the Yonge-University and Bloor-Danforth lines. These included four filters exposed on MOL technical staff riding on the trains to simulate passenger exposure.

All samples were collected during mid-day non-rush-hour periods. These samples were collected to assess exposure of TTC employees to asbestos (fibrous dust) in the subway. The standard method of analysis involves the counting of fibrous particles by an optical phase-contrast microscopy method. In this way the total fibre concentration is determined with no identification of fibre types. A fibre is defined as any observed particle (organic or inorganic) with a length to width ratio of 3:1 or greater and a length greater than 5 micrometers. The reported fibre concentrations represent the upper limits of asbestos fibre concentrations.

The results of the October 1976 survey appear in Table 5.1. The concentration of fibrous dust varied between not-detected (0.04 f/ml) to 0.2 fibres longer than 5 micrometers per millilitre of air (f/ml). Even if all fibres counted were asbestos, the concentrations would still be well below the Ontario recommended standard for exposure to asbestos of 2.0 f/ml (>5 um in length).

A representative cross-comparison analysis by electron microscopy techniques was performed on six of the 24 MOL samples. Electron microscopy is sensitive enough to resolve and detect all sizes of asbestos fibres and to identify their species. These results confirm the data obtained by the standard optical counting procedures. These analyses also indicated that no amphibole asbestos fibres were present. It can be concluded, therefore, that the Ontario recommended standard of 2.0 f/ml (>5 um in length) was not approached.

5.2 September 1977 Survey

The personnel samples collected during the 1976 survey were analysed only for fibrous dust, which the Working Group had originally identified as the major subway contaminant of concern. It became evident from the results of the analysis of the MOE filter samples (Section 4.1.2) collected during the 1976 survey that contaminants other than fibrous dust might be present at significant concentrations. The Working Group, therefore recommended that an additional survey of TTC employees' exposure to several other constituents of suspended particulate matter should take place.

On September 6 and 7, 1977, 30 filter samples of particulate matter were collected from breathing-zone air of TTC employees and simulated passengers (MOL staff). The sampling pattern was the same as for the 1976 survey, and as many of the TTC employees monitored in 1976, as were still available, were re-tested at the same job locations as in 1976.

The concentrations of the following substances were determined in these samples at the MOL laboratories:

Chromium (expressed as equivalent concentration
of the hexavalent oxide)

Iron (as ferric oxide)

Lead

Manganese

Nickel (elemental)

Zinc (as oxide)

The analytical results are presented in Table 5.2. For comparison, the Threshold Limit Values (TLV's) allowed in Ontario for these substances are as follows:

Substance	TLV (mg/m^3)
Chromic Oxide	0.05
Ferric Oxide	10
Lead	0.15
Manganese	5
Nickel (metallic)	1
Zinc Oxide	5

The results from Table 5.2 indicate that the guidelines were exceeded only for lead in two samples. Both instances were for a trackman working in the lower Yonge section of the subway system.

5.3 TTC Employee Blood Lead Level Survey (1978)

On the basis of the personnel monitoring results described in Section 5.2, the Working Group recommended that a survey be carried out for the concentrations of lead in the blood of selected long-term TTC subway employees in the occupations monitored in the 1976 and 1977 particulate matter surveys.

Blood samples were taken on April 3, 1978 from 24 such employees, including the trackman whose personnel sampling for lead showed an exposure level above the TLV. The analysis at the Occupational Health Laboratory, MOL, showed that the levels were all well below that which would be considered a hazard to employee health.

The highest result was 21 ug Pb/100 ml of blood and the average

for the group was 12.8 ug Pb/100 ml. The trackman whose personnel sampling showed a level above the TLV at College Station in September 1977, but who generally moves between stations, had a blood level below the average for the group.

Comment on these levels is given in Section 7.1.3.

TABLE 5.1

October 1976 MOL/TTC Occupational Sampling Survey

Sample No.	Job Description	Fibres Greater than 5 micrometers in length per ml of air
North-South (Yonge-University) Subway System		
October 19, 1976		
1.	Lawrence Station Ticket Collector	0.13
2.	Lawrence Station Cleaner	0.12
3.	Lawrence Station Track Man	0.09
4.	Train Driver/Guard*	0.06(0.3)**
5.	Train Guard/Driver*	0.06(0.2)**
6.	Simulated Passenger	0.13(0.8)**
October 20, 1976		
7.	Lawrence Station Ticket Collector	0.19
8.	Lawrence Station Cleaner	0.13
9.	Lawrence Station Track Man	0.17
10.	Train Guard/Driver*	0.07
11.	Train Driver/Guard*	0.07
12.	Simulated Passenger	0.07
East-West (Bloor Street) Subway System		
October 19, 1976		
13.	Pape Station Ticket Collector	0.03
14.	Pape Station Cleaner	0.14
15.	Pape Station Track Man	0.21
16.	Train Guard/Driver*	0.06
17.	Train Driver/Guard*	0.07
18.	Simulated Passenger	0.07

Table 5.1 October 1976 MOL/TTC Occupational Sampling Survey (continued)

October 20, 1976

19.	Pape Station Ticket Collector	0.04
20.	Pape Station Cleaner	0.10
21.	Pape Station Track Man	nd $<$ 0.04***
22.	Train Driver/Guard*	0.06(0.2)**
23.	Train Guard/Driver*	nd $<$ 0.04***(0.09)**
24.	Simulated Passenger	0.15(0.1)**

* The Driver and Guard on the trains rotate their positions. The sampling duration was over one and a half round trips. As an example, Sample No. 4., the person was the Driver for two legs of the trip and Guard for one.

** Comparison MOE values as measured by electron microscopy.

*** Not detected, less than 0.04.

TABLE 5.2

Analytical Results for Occupation Exposure (Sept 1977 Survey)

North-South Line, Lawrence Station, September 6, 1977	Chromium as CrO_3 mg/m^3 of Air	Iron Oxide mg/m^3 of Air	Lead mg/m^3 of Air	Manganese mg/m^3 of Air	Nickel mg/m^3 of Air	Zinc Oxide mg/m^3 of Air
1. Ticket collector	<0.02	0.36	0.03	<0.01	<0.01	<0.01
2. Janitor	0.02	0.25	0.01	<0.01	<0.01	<0.01
3. Trackman	<0.02	0.56	0.05	<0.01	<0.01	<0.01
4. Driver/ guard	<0.02	0.70	0.05	<0.01	<0.01	<0.01
5. Driver/ guard	<0.02	0.60	0.04	<0.01	<0.01	<0.01
6. Passenger	0.02	0.65	0.04	<0.01	<0.01	<0.01
North-South Line-Lawrence Station, September 7, 1977						
7. Ticket collector	<0.02	0.13	0.01	<0.01	<0.01	<0.01
8. Janitor	<0.02	0.29	0.02	<0.01	<0.01	<0.01
9. Trackman	<0.02	0.66	0.04	<0.01	<0.01	<0.01
10. Driver/ guard	<0.02	0.65	0.04	<0.01	<0.01	<0.01
11. Driver/ guard	<0.02	0.69	0.04	<0.01	<0.01	<0.01
12. Passenger	<0.02	0.63	0.04	<0.01	<0.01	<0.01
East-West Line-Woodbine Station, September 6, 1977						
13. Ticket collector	<0.02	0.08	<0.01	<0.01	<0.01	<0.01
14. Janitor	<0.02	0.24	<0.01	<0.01	<0.01	<0.01
15. Trackman	<0.02	0.33	0.01	<0.01	<0.01	<0.01
16. Driver/ guard	<0.02	0.14	<0.01	<0.01	<0.01	<0.01
17. Driver/ guard	<0.02	0.23	0.01	<0.01	<0.01	<0.01
18. Passenger	<0.02	0.20	<0.01	<0.01	<0.01	<0.01
East-West Line-Woodbine Station, September 7, 1977						
19. Ticket collector	<0.02	0.15	0.01	<0.01	<0.01	<0.01
20. Janitor	<0.02	0.15	<0.01	<0.01	<0.01	<0.01
21. Trackman	<0.02	0.33	0.01	<0.01	<0.01	<0.01
22. Driver / guard	<0.02	0.31	0.01	<0.01	<0.01	<0.01
23. Driver / guard	<0.02	0.19	<0.01	<0.01	<0.01	<0.01
24. Passenger	<0.02	0.25	0.01	<0.01	<0.01	<0.01

TABLE 5.2 (continued)

North-South Line-College Station, September 6, 1977

	Chromium as CrO_3 mg/m^3 of Air	Iron Oxide mg/m^3 of Air	Lead mg/m^3 of Air	Manganese mg/m^3 of Air	Nickel mg/m^3 of Air	Zinc Oxide mg/m^3 of Air
25. Ticket collector	0.2	0.14	0.02	<0.01	<0.01	<0.01
26. Janitor	0.2	0.72	0.05	<0.01	<0.01	<0.01
27. Trackman	0.3	8.11	0.48	0.05	<0.01	1.0

North-South Line-College Station, September 7, 1977

	Chromium as CrO_3 mg/m^3 of Air	Iron Oxide mg/m^3 of Air	Lead mg/m^3 of Air	Manganese mg/m^3 of Air	Nickel mg/m^3 of Air	Zinc Oxide mg/m^3 of Air
28. Ticket collector	<0.02	0.06	0.01	<0.01	<0.01	<0.01
29. Janitor	<0.02	0.64	0.04	<0.01	<0.01	<0.01
30. Trackman	0.02	5.49	0.17	0.02	<0.01	0.01

< Indicates not detected at the level stated.

6.0 MATERIALS AND EQUIPMENT TEST PROGRAM

6.1 Brake Shoe Evaluations

6.1.1. Composition Brake Shoes

The TTC has been using composition (to differentiate from traditional cast-iron) brake shoes since approximately 1955. The original supplier was the Railroad Friction Products Corp., now represented in Canada by WABCO Limited. This company, as well as others in the field, regard their formulation of friction material as proprietary; therefore, the TTC has little idea of the formulation of the material. It is known that developers try many different mixes. Formulation and dynamometer-testing, which are often undertaken to arrive at a marketable product, are expensive processes hence the secrecy when a successful formulation is found.

Several years after the TTC adopted the Railroad Friction Products Cobra brake shoe (their "W-238" mix) the Griffin Steel Foundries Co. introduced their competitive Anchor brake shoe. In time, the Cobra W-238 mix was superseded by the W-278, which was of slightly different formulation and intended to have less tendency to squeal.

Along with the brake shoes that were used by the TTC, new lead/asbestos-free brake shoes were introduced and tested on subway vehicles for mileage, wear capability, and stopping distance. In addition, extensive analytical tests were conducted for lead and asbestos and other contaminants by Ontario Research Foundation.

Samples of several types of subway car brake shoe currently in use (a new and a used specimen of each type) were subjected to electron microprobe XRF analysis and scanning electron microscope (SEM) examination to

determine their approximate gross elemental and material composition. The qualitative results of this work are presented in Table 6.1. These XRF and SEM results from ORF corroborated preliminary qualitative findings by the MOE Physical Methods Laboratory. The MOE laboratory examined five brake shoe samples by X-ray diffraction and optical microscopy. Their results are summarized in Table 6.2(A). Subsequently, the brake shoe materials were subjected to semi-quantitative elemental analysis at ORF. The results of these determinations are listed in Table 6.3.

6.1.2 TTC Subway Car Types

The types of subway cars operated by the TTC are quite different with regard to brake shoes. Basically, there are two major categories; those without and those with electrodynamic braking, as described in Sections 3.1 and 3.2.

The TTC's fleet consists of 134 cars without electric braking (Gloucester ('G') cars) and 632 cars with electrodynamic braking (Montreal Locomotive Works ('M') cars and Hawker-Siddeley Canada Limited ('H') cars). The 'G' cars use 16 brake shoes per car of a style designed to fit a London Transport brake shoe head. The only current supplier of such a shoe is Griffin, who have apparently found it economic to make the product for the single Canadian customer.

The 'M' and 'H' cars have brake shoe heads designed to accept a standard Association of American Railroads (AAR) brake shoe. Consequently, both Anchor and Cobra and others will provide shoes for this application. Because of the reduced duty on the friction brake due to introduction of electric braking, the 'M' and 'H' cars use only eight brake shoes per car.

Recent investigation and trial has shown that it is possible to modify the brake shoe heads on 'G' cars so that they will accept AAR style brake shoes.

6.1.3 Lead-Free Brake Shoes

In 1975 WABCO Limited advised that they had available a "lead-free" Cobra brake shoe in their W-392 mix, and they delivered some samples to the TTC for trial in August of that year. In November 1975 the AAR approved Cobra W-392 brake shoes for use on railroad freight cars.

In mid-1976 WABCO Limited informed the TTC that due to manufacturing process emissions regulations by the USA Environmental Protection Agency, their American parent was forbidden to produce any more W-278 mix, and that W-392 was to be the sole allowable alternative. The TTC then had to complete the testing earlier initiated, and, for competitive reasons, obtained some Tiger lead-free brake shoes being manufactured by Abex Industries Limited.

6.1.4 Brake Shoe Performance Results

1) Cobra W-392

The lead-free Cobra W-392 shoe was tested on both 'G' cars (having modified brake shoe heads) and on 'M' and 'H' cars. In all cases, the shoe coefficient of friction was satisfactory, producing car-stopping distances as were obtained with the superseded W-278 mix. The W-392 shoe does not produce undesirable side effects such as squeal or grooved wheel treads. The rate of shoe wear is reduced, and greater shoe life is being obtained compared with the W-278 shoe.

2) Tiger

The lead-free Tiger shoe was tested only on 'G' cars having modified brake shoe heads. Performance in all respects but one was comparable to that of the Cobra W-392. The exception was shoe life, which was much less.

3) Anchor Lead-Free

Griffin Steel Foundries has produced a limited number of lead-free shoes for testing by the TTC. Testing has shown that the first mixes offered have wear rates that are excessive (greater than that of the Tiger). Anchor is continuing its development program.

Results of recent tests and earlier data for comparison are shown in Table 6.4.

A compilation of brake shoe data obtained from manufacturers or by analysis is shown in Table 6.5

The test results indicate that the Cobra lead-free W-392 brake shoe is superior in performance on both 'G' and 'M'/'H' cars to all other shoes tested, both with and without lead. It is understood that the economics of purchase are also in favour of the Cobra W-392.

The shoe performance together with its practically zero-lead content make the Cobra W-392 brake shoe a satisfactory product, and its use has been recommended by the TTC as standard on both 'M' and 'H' cars and on 'G' cars after suitable brake shoe head modification.

Observation must be made of long-term effects on car wheel life, as they are not discernible in short-term tests.

The TTC has recommended that brake shoes offered by competitors be tested in order to develop an alternative source of supply.

6.2 Acoustic Wall Lining Material

The MOE, in co-operation with the TTC, collected samples of acoustic material from walls at various locations in the subway system.

The various types of acoustic material used in the subway system are CAFCO Sound Shield "85", Kilnoise, Fiberglas, and Limpet. Except for Fiberglas, which is fastened, the material is sprayed onto the walls. The acoustic material is used mainly for noise attenuation.

The following stations were selected for sampling by the MOE:

> Main Street, Woodbine, Sherbourne, Yonge, Bay, St. George, Dufferin, and Jane on the Bloor-Danforth subway, Lawrence on the northern extension of the Yonge subway, Bloor on the Yonge subway, and Museum on the University subway

The various types of acoustic material were used as follows in the system:

- Fiberglas in the original Yonge subway
- Limpet in the University subway
- Sound Shield "85" in the Bloor-Danforth and Spadina subways
- Kilnoise in the northern extension of the Yonge subway

Samples of subway tunnel acoustical insulation were subjected to electronmicroprobe XRF analysis and SEM examination by ORF to determine their approximate elemental and material composition. The qualitative results of this work are presented in Table 6.1(B). These XRF and SEM results from ORF corroborated preliminary qualitative findings by the MOE Physical Methods Laboratory. The MOE laboratory examined 12 acoustical insulation samples from the subway by X-ray diffraction and optical microscopy. Their results are summarized in Table 6.2(B).

6.3 Wall Washing

Subway wall washing is a regular part of the maintenance program on the system. In an effort to evaluate the effects of wall washing in reducing the total suspended particulate in the system, a wall-wash program was undertaken in two areas of the subway as follows:

TABLE 6.2

X-ray Diffraction and Optical Microscopy Analysis of Brake Shoes and Acoustical Lining Samples

(Ministry of the Environment)

A. Brake Shoe Analysis:

Sample	Composition
1	Pb, C (graphite), Sn
2-5	PbS (galena), aluminum silicate (Sillimenite), chrysotile.

B. Tunnel Lining Analysis:

Sample	Composition
Bay Station (upper) Sherbourne Stn. Woodbine Stn. Bay Stn. (lower) Main Street Stn. Dufferin Stn. Jane Stn.	calcite + glass fibre
Museum	chrysotile + glass fibre
St. George Stn.	chrysotile + glass fibre
Lawrence Stn.	chrysotile + glass fibre
Sound Shield (2 samples)	$CaCO_3$ (calcite) + glass fibre

TABLE 6.3

Approximate Chemical Composition of Subway Brake Shoe Types

(major components)

Brake Shoe	Service	Iron	Lead	Asbestos
Cobra 392	M & H, G	10.6%	0.03%	11.4%[b]
Cobra 238 (278)	M & H	13.4	16.3	c
Anchor H-4A	M & H	30	9.8	c
Anchor H-51	G	-	13.6	9.5[b]
Abex "Tiger"	test	20	ND	ND
Griffin "low lead"	test	20.2	6.6	c

NOTE: The other major component of all of the above brake shoe types is carbon (graphite).

- = Not analysed.

ND = Analyzed, but none detected.

b = Information supplied by manufacturer.

c = Qualitatively identified as a significant component, but not analyzed quantitatively.

TABLE 6.4

TEST RESULTS

WEAR RATES OF BRAKE SHOES

SUBWAY CARS

Brake Shoe Type	Car Type	Brake Shoes/ Cars	Miles/Shoes (2" Thick)
Anchor (with Lead)	G	16	16,000
Anchor (Lead-Free)	G	16	6,000
Tiger	G	16	10,000
Cobra W-392	G	16	37,000
Cobra W-278	M & H	8	55,000
Anchor (with Lead)	M & H	8	54,000
Cobra W-392	M & H	8	70,000

TABLE 6.5

BRAKE SHOE DATA

1. Characteristics:

Shoe Type	Spec. Wt. gm/cubic cm.	Lead Content by Weight
Anchor (Std.)	2.42	8½%
Cobra (Lead free) (W-392)	1.68	1½-2%
Comet (Std.)	2.2	20%

2. Brake Shoe Wear:

2.1 Gloucester Cars (Friction Brake Only)

Number of Gloucester cars	- 134
Brake Shoe Type	- Anchor, Std. (prior to conversion to Cobra W-392)
No. of shoes per car	- 16
Average car miles per year	- 75,740
Average life of brake shoes	- 16,000 miles (37,000 miles for W-392)
Average volume abraded per brake shoe	- 44 cu. in.
Rate of abrasion	- .00275 cu. in/shoe mile
Rate of abrasion	- .044 cu. in/car mile
Specific Weight	- 2.42 gm/cc
Specific Weight	- .0874 lb/cu. in
Rate of abrasion	- .0038 lb/car mile
	- 291.28 lb/car year
	- 39,030 lb/fleet year

2.2 M&H Subway Cars (Electrodynamic Brake)

Number of cars	- 360 (at time of survey)
Brake shoe type	- Cobra (W-392)
Number of shoes per car	- 8
Average car miles per year	- 67,520
Average life of brake shoe	- 70,000 miles
Average volume abraded per brake shoe	- 42 cu. in
Rate of abrasion	- .0006 cu. in/shoe mile
Rate of abrasion	- .0048 cu. in/car mile
Specific weight (approx.)	- 2.3 gm/cc
Specific weight (approx.)	- .083 lb/cu. in
Rate of abrasion	- .0004 lb/car mile
Rate of abrasion	- 27 lb/car year
Rate of abrasion	- 9,720 lb/fleet year (at time of survey
Rate of abrasion	- 13,446 lb/fleet year (after January, 1978)

7.0 INTERPRETATION OF RESULTS

7.1 Health Effects of Contaminants in the Subway System

7.1.1 Asbestos

Sampling for asbestos undertaken as part of the Ministry of Environment survey in 1975 and early 1976 showed that in some subway station locations there was asbestos present in amounts thought to be undesirably high in view of the ambient air guideline. The survey in October 1976 did not indicate any substantial change in this situation.

It is believed that although use of the subway system is considered to be no more than two hours per day for each passenger, consideration must be taken of the possible amount of asbestos to which any member of the general public might be exposed in the course of city life, not only that incurred as a result of subway travel. Any effect would possibly not become obvious for over 30 years, and there is no method of monitoring subway users to see if an adverse effect should occur. The very young are exposed as well as those in adult life; therefore, there is added responsibility to ensure that this possible hazard to health is reduced to a minimum consistent with adequate functioning of the subway system.

In this situation the concern would be related to two forms of cancer: lung cancer and mesothelioma. Lung cancer is a major cause of death for males, increasingly so for females, and is linked to cigarette smoking. It is also increased in asbestos workers, particularly asbestos workers who smoke. It is a more common cause of death in urban than rural areas.

It would be impossible with the present state of knowledge to assess the impact of overall community asbestos exposure, including exposure during subway travel, on mortality from lung cancer.

Mesothelioma (pleural and peritoneal) is a rare form of cancer affecting the lining membrane of body cavities. It affects perhaps one to two persons per million of the population per year. In recent years, possibly because of awareness of its possible association with asbestos exposure and improved diagnosis, it has been more readily reported. It would be hard to know of any real increase in its incidence. There are several studies relating its occurrence to 'neighbourhood' links with asbestos exposure and in family contacts of asbestos workers, but such contamination was probably heavy. There are also cases of the disease in these studies in which no association with asbestos has been found. So far, there is no evidence of an excess risk of this disease in members of the general public from chrysotile asbestos exposure.

There is almost certainly a dose-response relationship, but, for any group exposed, the possible importance of short-term high exposures compared to long-term low exposures is not known.

In summary, there is no evidence to suggest that exposures to chrysotile asbestos such as those measured in the TTC subway would have a deleterious health effect on passengers. However, it is still extremely important that asbestos levels are kept as low as can possibly be achieved because of the uncertainties involved.

7.1.2 Total Suspended Particulates

The ambient air quality criterion for TSP (no size specification) is 120 ug/m^3 of air averaged over 24 hours, or 60 ug/m^3 of air (geometric mean) averaged over one year.

The TSP concentrations of eight samples collected by high-volume samplers at form stations (two samples per station) over periods of 18 to 24 hours on the 19th and 20th of October, 1976 were as follows::

1) Lawrence Station: 2503 ug/m^3 and 2267 ug/m^3;
2) College Station: 1126 ug/m^3 and 1018 ug/m^3.
3) Queen's Park Station: 1047 ug/m^3 and 857 ug/m^3.
4) Woodbine Station: 305 ug/m^3 and 148 ug/m^3.

The Threshold Limit Values (a U.S. guideline used in industry and government to determine acceptable concentrations) for mixtures were calculated for the personnel samples obtained from the 1977 MOL survey. Because two individual samples for lead exceeded the TLV, the TLV for mixtures was also exceeded for these samples. The results for all other samples were below the TLV for mixtures. The TLV for mixtures was calculated because of the possible additive effects of the elements in the dust. In the case of mixtures, the Threshold Limit Value of the mixture was considered to be exceeded if the following sum exceeded unity:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n}$$

where C = concentration in milligrams per cubic meter and T = the TLV

7.1.3 Lead

The results of high-volume sampling for lead in the subway system showed high levels at several locations (notably Lawrence Station, College Station, and Sheppard Station) well above the ambient air criterion of 5 ug/m^3 over a 24-hour sampling period.

The highest individual sampling result for lead was 93.7 ug/m^3 at Lawrence Station on October 19, 1976.

Calculations have been made of the blood lead levels likely to be present in the average subway passenger in Toronto. In order to do this, certain necessary assumptions have been made:

1) The particle sizes of the lead in the subway system correspond to the sizes reported at Queen's Park Station on 19 and 20 October 1976.

2) The particle size of lead in ambient air in the city falls within a range of particle sizes given by the International Commission on Radiation Protection (ICRP); blood volume is 5200 ml* for purposes of calculating minimum and maximum fractional uptakes of lead into blood.

3) The average ambient air concentration of lead in the city of Toronto is 2 ug/m^3.

4) Passengers use the system for a maximum of two hours per day for five days a week at a breathing rate of 1.25 m^3/hr.

5) The equilibrium blood burden is 49.6 daily intakes (based on the Retention Function described by Bernard **).

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*ICRP, Report 23 of the Task Group on Reference Man, Pergamon Press (1975).

** Bernard, S.R., "Dosimetric Data and Metabolic Model for Lead," Health Physics, 32, 44-46 (1975).

6) The usual intake of lead in food and water is 160 ug/day* and the fraction entering the blood stream from the gastro-intestinal tract is 1/10 of this amount (i.e., 16 ug/day).

For the average Toronto citizen not using the subway system, it is assumed that exposure to lead comprises absorption from ambient air levels plus absorption from food and water.

For a subway traveller, two hours in the subway system is the time in which he/she is exposed to subway air instead of ambient air. The average levels for lead on the north/south line found in October 1976 were used in this determination (56.4 ug/m^3).

Based on these assumptions, the calculated blood lead level for the subway traveller is as follows:

Exposure	Lead Levels in Blood ug/100 ml	
Period(y)	Non-Subway Users	Subway Users
1	7-10	14-17
2	10-14	20-24
5	12-19	26-32
10	14-21	29-36
15	15-23	32-39
25	16-24	33-41
75	18-27	37-45
Equilibrium	18-27	38-46

(Details of calculations and graphic representation of particle deposition in the respiratory tract and an alternative approach to the method of study are given as Appendix D).

* Effect on Human Health of Lead from the Environment, Ontario Ministry of Health, 1974.

These calculated blood levels, developed from using the foregoing assumptions, indicate that a substantial contribution to total intake of lead may result from long periods of subway use. If there is exposure to lead over and above that normally experienced from ambient air in Toronto, and there is also subway use, an undesirable level of lead in blood might be reached, according to this model.

The results of the worker blood-lead monitoring survey were summarized in Section 5.3. Briefly, the highest result was 21 ug Pb/100 ml of blood and the average for the group of 24 TTC long-term subway employees was 12.8 ug Pb/100 ml. The trackman whose personnel sampling showed a level above the TLV during the September 1977 survey had a blood lead level below the average for the group.

The level of lead in blood at which symptoms of ill-health might be found varies considerably from one person to another. In general, symptoms of lead poisoning would not occur with a blood lead level below 70-80 ug/100 ml.

However, certain biochemical changes, which reflect increased absorption, take place at lower blood lead levels. The significance of these changes in relation to development of measurable health effects is not fully understood, particularly since the amount of absorption is often not clearly known and the rates of absorption and of excretion will vary in different situations for short-term and long-term exposure.

These changes are principally seen in the haemopoetic (blood forming) system and in the nervous system. At a level of about 50 ug lead per 100 ml of blood, haemoglobin production may be affected.

Lead has an effect on certain enzyme systems concerned with heme synthesis and on circulating red blood cells, but any such effect would not be clinically observable at the levels calculated within this study, even after long periods of subway use.

In summary, there is no immediate or acute threat to the health of persons using or working in the subway system. If the levels of lead found in the system were to increase, undesirable biological alterations might occur in regular users over many years and might, in turn, lead to clinical illness. Measures to reduce exposure are in hand and are described elsewhere in this report.

7.1.4 Iron and Carbon

There is no evidence that inhalation of iron is harmful. Occupational exposure to a level of respirable particles or fumes of iron oxide for prolonged periods have been associated with the development of scattered opacities in the lungs visible in chest X-rays. These opacities, considered to be due to iron pigmentation, do not appear to lead to scarring of the lung or predisposition to any lung disease. The level for occupational exposure to iron oxide is set at 10 mg/m^3 as an 8-hour time-weighted average to avoid these X-ray changes. There is no recommended iron level for ambient air in Ontario.

Carbon (presumably largely graphite) eroded from brake shoes is present in the subway air. The percentage of the element present in the total suspended particulate matter obtained from high volume sampling from March to April 1977 at two subway stations is shown in Tables 4-9 and 4-10. A graphite pneumoconiosis, somewhat similar to coal miners' pneumoconiosis, has been described in workers employed for many years in the graphite mining industry. The percentages of carbon in the total suspended particulate matter are not comparable to the levels at which any effects on the respiratory system might be seen. The Threshold Limit Value for occupational exposure to graphite in the workplace is 5 mg/m^3 respirable, which also protects against the effects of any free silica that may be present in natural or synthetic graphite.

7.2 Evaluation of October 1976 Tests

The range of asbestos fibre concentrations for the October 1976 survey is very similar to that of the preliminary survey results on samples collected in May 1975 and April 1976, namely, up to 0.3 fibres longer than 5 um per milliliter of air averaged over two or three hours.

The concentration of asbestos fibres longer than 5 micrometers in 19 of the 52 samples exceeded the Ministry of the Environment guidelines of 0.04 fibres/ml 5 um in length and was near the guideline level in a few other samples. The guideline for fibre concentration, however, refers to samples collected over a continuous 24-hour period and relates to 24-hour continuous exposure of a receptor to that concentration. The relationship between the exposure guideline and the actual exposure of a TTC passenger is not clear, since very few members of the public would spend more than 2 hours per day in the subway system.

The MOE ½-hour ("point of impingement") guideline of 5 micrograms per cubic meter was exceeded by only one of these samples, the maximum mass concentration being 20 micrograms per cubic meter calculated from the total fibre count, 88 per cent of which was based on the mass of a single very long fibre. The maximum mass concentration of the remaining samples was 2.5 micrograms per cubic meter.

The TSP data in Table 4.2 present a somewhat different situation. Both ½-hour (100 ug/m^3) and 24-hour (120 ug/m^3) standards were exceeded at all of the monitored stations on the Yonge-University line on both days of tests.

The Sheppard vent results in Table 4.2 show that ambient air entering the system is not responsible for the elevated levels of TSP, since measurements of contaminants flowing out of the vents greatly exceed those being sucked into the vents.

The chemical analysis of TSP as documented in Table 4.2 indicates that iron and lead are the two elements (of those analyzed) which are present in elevated concentrations. A third major constituent, carbon, was identified during the follow-up studies. Roughly 50 per cent of the total suspended particulate matter in the subway is iron (as elemental Fe). This is typical of subway air in a system in which iron wheels run on iron rails. An additional source of iron in subway TSP is the erosion of the brake shoes themselves (see Tables 6.1 and 6.2).

The high concentration of lead in the TSP within the subway system appears to arise also from the brake shoes, as inferred from several pieces of information. Foremost is the fact that heavy TSP loadings occur only on the Yonge-University line where mechanical braking (Gloucester cars) predominates over electrodynamic braking ('M' and 'H' cars) and is heaviest at those stations surveyed where braking is most prolonged (Queen's Park and Lawrence). The size distribution of both iron- and lead-containing particles (see Table 4.2) is consistent with production by mechanical erosion. That is, both iron and lead predominate in the larger-size particles. Lead from automobile sources and smelters, for example, normally predominates in the smallest size fraction as collected by an Andersen sampler.

The major constituents of the collected subway TSP (C, Pb, Fe) were also the main constituents of the brake shoes (see Tables 6.1 and 6.2) in use at the time of the 1976 survey.

It was possible for either or both of the brake shoes or acoustical insulation to produce the pattern of asbestos concentrations that was observed. Both materials are known to contain some asbestos. The most reasonable interpretation, however, is that the brake shoes were a major contributor to airborne asbestos. The amount of energy in the movement of air through the tunnels is insufficient to comminute the very long fibres of asbestos present in the University and North Yonge acoustical insulation to the very short fibre lengths that dominate the collected samples.

The fact that the total asbestos fibre concentration (including fibres shorter than 5 micrometers) in the College Station (where the tunnel lining consisted of fibreglass and contained no asbestos) samples was comparable to that of the Queen's Park/Lawrence/St. Patrick/Sheppard samples also implicates brake shoe erosion as a major contributor to airborne asbestos.

More definite conclusions were possible on the basis of results from the follow-up surveys and tests, as described in the following sections.

7.3 Subway Equipment Characteristics

7.3.1 Tunnel Wall Washing and Fan Tests

Of the four tests carried out at Queen's Park Station, multiple wall washings decreased the COH value by less than 10 per cent in three cases and 15 per cent in the fourth. Three consecutive wall washings were performed in the early morning of February 15, 1977; six washings, on February 16, 1977. However, they produced very little improvement. Although the peak morning COH on February 15 represented a 22% from February 14 when no wall washings occurred, the peak morning COH value increased on February 16 after 6 washings, and the overall average on the 15 was not significantly different from that on February 14. Ventilation fans operating during these tests showed no significant improvement in COH levels.

The low nighttime COH values imply that large quantities of dust settle out when trains are not running, and that re-entrainment may be appreciable. If the extensive multiple wall-washings of February 15 & 16 had an effect of removing the settled dust, however, the COH value in the morning of the 16th did not support such a conclusion, since it showed no improvement. The implication, therefore, is that the subway trains are responsible for generating these large amounts of particulate daily. Furthermore, intensive tunnel washing is not likely to alleviate the observed airborne particulate loading significantly.

7.3.2 Ambient Particulate Tests

The COH values, indicators of TSP concentrations, are similar on both subway lines during the 0200-0600 period of no-service when typical hourly maximum ambient air quality values are approached (Table 4.8). They increase drastically during service, especially on the Yonge-University line and correspond closely to peak subway traffic periods (Tables 4.6 and 4.7). The fact that the COH value is closely related to the frequency of trains (Figure 4.2)

substantiates the hypothesis that the subway trains are directly responsible for the generation of a major portion of the particulate.

The three Sunday tests were designed to isolate the car type most responsible for the particulate emissions, and, although based on a limited amount of data, dramatic differences were found between the 'G' and 'H' cars. The implication is that because of the different braking system and larger number of brakes per car, brake wear of the 'G' car is a major contribution to emissions.

Figure 4.2 was developed from multiple regression analysis relating COH with the frequency of 'G' and 'H' cars passing through Lawrence and Bay Stations (development shown in Appendix C). At Lawrence Station, the slope of the COH vs. 'G' frequency graph is three times the corresponding slope for 'H' cars, indicating that each Gloucester car produces three times as much particulate matter as each Hawker-Siddeley or Montreal Locomotive Works car. The linear relationships between COH and car frequency for 'H' cars measured at the Bay and Lawrence Stations are similar, indicating a certain reproducibility. The background particulate level (intercept) for Bay Station is 20 per cent lower than for Lawrence Station. This difference could be due to the higher speeds of the trains entering Lawrence Station (40 per cent to 50 per cent higher than at Bay Station). Higher train speeds results in heavier applications of brakes to bring trains to a stop and the generation of greater wind forces by which particles are re-entrained.

Tables 4.9 and 4.10 detail the TSP loading and the amounts of iron, carbon, and lead in the Hi-Vol samples. As determined from the COH relationships, the TSP concentrations are on the order of 2.5 times greater at Lawrence Station. Not only can this be related to the extra brake wear of shoes on the 'G' cars, but it must also be attributed to the speeds at which the trains enter the station. The mean TSP has been calculated only for weekday data since normal scheduling was in operation, but a comparision of the Sunday car tests on April 24

1977 ('G' car test) and on May 1, 1977 ('H' car test) confirms the consistently higher production of particulate by the 'G' cars on the Yonge-University line.

The high percentages of iron are similar at both Bay and Lawrence Stations, but the iron values at Bay Station appear more consistent from day to day. This could be attributed to the varying ratios of 'H' and 'G' cars operating on the Yonge line. The day of the 'G' car test, the percentage of iron was 46 per cent; during the 'H' car tests, it was was 57 per cent. A previous analysis of the brake shoes used indicated that the Cobra W-392 shoe used on 'H' cars contained metallic iron in the form of finely divided particles, while in all other brake shoes iron was present in larger fragments. When the brakes are applied, iron particles may be more easily released from the Cobra W-392 shoe.

If the relative proportions of lead, iron, and carbon in the various brake shoe types are known, it is possible, in principle, to compare these proportions with the measured proportions of the same substances in subway airborne particulate matter to determine the relative contribution of brake shoe dust to the total loading.

Such a comparison proved to be difficult, in practice, because of the mixture of car and brake shoe types, different patterns of brake application at test stations, and normal variability in sampling and analysis procedures.

Analyses of carbon in the samples at both stations are very similar with only a small scatter.

The largest difference between the two stations was found in the elemental lead concentrations. As shown in Tables 4.9 and 4.10, the mean at Lawrence Station is more than three times the mean at Bay Station. There is little doubt that airborne lead particles are a result of brake shoe emissions, but from available information, it would not be possible to determine what the specific mix of brake shoes (they contain various proportions of lead) was on 'G', 'H' and 'M' cars during the survey period. The consistently low concentrations of lead on the Bloor-

Danforth line suggest that the brake emissions from the 'G' cars are responsible for the elevated lead concentrations on the Yonge line. In addition, the Cobra W-392 brake shoe, which is indicated to have been on most of the 'H' and 'M' cars at the time but not the 'G' cars, has a very low lead content, as analyzed by Ontario Research Foundation.

Table 7.1 summarizes the TSP and elemental analyses for the 'G' and 'H' car tests and the average weekly values.

7.3.3 On-Train Particulate Tests

The results for each test of parallel sampling with the Hi-Vol and the Andersen sampler during the on-train survey compare closely. The two 'G' tests performed on August 16 and 17, 1977 yielded almost identical results. Compared to these results, the 'H' car test showed 33 per cent less TSP, 45 per cent lower lead concentrations, 38 per cent less iron, and 20 per cent less carbon. The copper concentrations were similar for all tests.

As indicated in Table 4.11, the particulate concentration aboard the 'H' car is of the same order as the trackside particulate concentration at Bay Station ('H' cars only) and the 'H' car Sunday test result on the Yonge line. The same can be said for the 'G' car concentrations and the comparable values found at trackside at Lawrence Station during the week ('G' and 'H' cars) and during the 'G' car Sunday test ('G' cars only). The on-train tests were performed on days when both 'G' and 'H' cars were running; again, the concentrations seem to be a direct result of braking and other train emissions and not of re-entrained dust.

Although based on a limited number of data, the small copper concentrations are similar for both types of car, which suggests either a source external to the cars (i.e., ambient air entering the tunnel system through the vents) or common sources inside all the cars (e.g., electrical gear, motors). The very

high ratios of lead and iron concentrations to copper concentrations compared to typical ambient air values also demonstrate conclusively that the former contaminants are emitted in the subway system.

7.3.4 Identification of Sources-Summary

From the wall washing experiments, a decrease of typically less than 10 per cent (one case, 15 per cent), was observed in the COH value after successive wall washings. Since instrumental and reading errors are high because of the high particulate levels in the tunnel atmosphere and the abnormal environmental operating conditions, statistical variance of COH reading is high. Thus, a 10-15 per cent decrease is not sufficient to support a conclusion that wall washings would lower the concentration of the suspended particles significantly. The low nighttime values of COH and the relatively small effect of a large number of multiple wall washings performed on consecutive days suggest that re-entrainment of settled dust is not a major contributor, but that large amounts of particulate are generated daily.

The COH values during the trackside survey at Lawrence and Bay Stations correlate with the frequency of trains, and peak values correspond to peak traffic periods. The trains, therefore, are directly responsible for a major portion of the particulate.

These emissions to ambient air do not have a significant impact on ambient air quality, because they are very small relative to emissions from the numerous other sources of airborne particulate matter in the city--vehicle traffic and combustion sources, for example.

The Sunday car tests showed the Gloucester cars to be responsible for about two times more particulate emission than the Hawker-Siddeley cars. To further substantiate this, the relationships between COH and the frequencies of 'G'

and 'H" cars during weekday operation imply that particulate emissions from 'G' cars are about three times greater than those from 'H' cars. The elevated concentrations of iron, lead, and carbon (major constituents of the brake shoes used) implicate the brakes as a major source of particulate emissions from both the 'G' and 'H'/'M' trains while the type of braking system is responsible for the relatively higher emissions from the 'G' cars. The Fe, Pb, and C concentrations are consistently the same proportion of the TSP, especially during exclusive use of 'G' or 'H' cars, even when the absolute magnitude of TSP varies. Copper, which is not known to be a constituent of the brake shoes and which is always present in ambient TSP, is low in subway TSP and shows little variability. These facts would indicate also that the large Fe, Pb, and C emissions are related to the trains. As calculated from the mean values in Tables 4.9 and 4.10, these three elements account for a minimum of 60 per cent (expressed as metallic elements) of the total suspended particulate measured to a maximum of over 90 per cent (expressed as chemical compounds) depending on the chemical form in which they occur (Fe, Fe_2O_3, Fe_3O_4, etc. and similarly for Pb).

It is worthwhile to note that the TSP and elemental concentrations measured on-train are comparable to those measured during the trackside surveys. It can be concluded that the air quality in the cars is similar to the air quality in the tunnels and on the station platforms. The size fractionation data show the particulate size distribution to be virtually the same for the 'G' and 'H' cars with 75 per cent of the particulate mass concentrated in particles greater than 2 um in diameter and about 10 per cent concentrated in the sub-micron range ($\leqslant$ 1.1 um). The size fraction breakdowns of the elemental analyses for the two 'G' car tests are also similar. In every test and for all elements, the second stage of the Andersen sampler (3.3 to 7 um) collected the largest fraction of the mass, while a relatively small proportion of the mass was concentrated in the submicron size range ($\leqslant$ 1.1 um).

7.3.5 Effect of Equipment Changes and Opening of Spadina Line on Subway Air Quality

A reasonable assumption, which will allow an approximate calculation of the effect on measured TSP or (COH) of various changes to the operating conditions or equipment characteristics and which is strongly supported by field measurements, is that measured TSP (or COH) is proportional to brake shoe wear rates (see Section 7.3.2.). That is, it can be assumed that the abrasion rates of brake shoes of both 'G' and 'H' cars (tabulated in Table 6.5) are linearly related to measured TSP (and COH) values. Appendices B and C provide the basis for assuming these relationships.

7.3.5.1 Baseline Data for the Yonge-University (Spadina) Line

The baseline against which the following changes are compared is the set of measured TSP and COH values from 1976 and 1977, as documented in Chapter 4 and Appendices B and C, and the equipment in service at that time.

Changes to the operating conditions and equipment characteristics on the north-south lines (Yonge-University-Spadina) are most important for improving subway air quality. The equipment in use on the Yonge-University line in 1976-77, therefore, is the basis for comparison. This equipment consisted of 134 'G' cars and about 120 'M'/'H' cars on average (referred to in the following as 'H' cars).

All of the following calculations are approximate but sufficiently quantitative to indicate the relative magnitudes of the effects of various equipment changes.

7.3.5.2 Effect of Converting 'G' Car Brake Shoes

The TTC has been converting brake shoe mountings on 'G' cars to accomodate the Cobra W-392 shoe since 1977. By the end of 1979, all of the 134 'G' cars had been so converted and equipped with the Cobra shoes. This shoe wears much longer than the older 'G' car shoe types (see Tables 6.4 and 6.5), and particulate emissions have been considerably reduced.

With Cobra shoes on 'G' cars, brake shoe emissions from the 1976-77 Yonge-University fleet totalled approximately 42,270 pounds a year, as indicated below:

Equipment		Approximate, Calculated Annual Brake Shoe Emissions (1976-77 fleet)
134 'G' cars		39,030 lb.
120 'H' cars		3,240 lb.
	Total	42,270 lb.

With Anchor shoes on 'G' cars, brake shoe emissions from the 1976-77 Yonge University fleet now total approximately 24,040 pounds a year, as indicated below:

		Approximate, Calculated Annual Brake Shoe Emissions (1976 and 1977 fleet)
134 converted 'G' cars		20,800 lb.
120 'H' cars		3,240 lb.
	Total	24,040 lb.

The corresponding percentage decrease in emissions is

$$\frac{42,270 \text{ lb} - 24,040 \text{ lb}}{42,270 \text{ lb}} \times 100 = 43 \text{ per cent}$$

7.3.5.3 Effect of Replacing 'G' Cars by 'H' Cars

If all of the converted 'G' cars were to be taken out of service and replaced by an equivalent number of 'H' cars (six 'H' cars for every eight 'G' cars), brake shoe emissions would be reduced further on the Yonge-University-(Spadina) line and would only total approximately 5,940 pounds, as indicated below:

Equipment	Approximate, Calculated Annual Brake Shoe Emissions (all 'H' fleet) 1976/77 Base.
220 'H' cars	5,940 lb.

The additional percentage decrease in annual brake shoe emissions for the "all-'H' fleet" compared with the fleet consisting of 'H' and converted 'G' cars is

$$\frac{24{,}040 - 5{,}940}{24{,}040} \times 100 = 75 \text{ per cent}$$

7.3.5.4 Effect of Opening the Spadina Line

The most important parameter related to air quality is the frequency of 'G' cars passing any given point in the system (cars per hour). The 'H' cars, which were added to the fleet of cars on the north-south lines with the opening of the Spadina line, had the effect of reducing the frequency of 'G' cars proportionately. The number of 'H' cars in the Yonge-University-Spadina fleet increased from about 120 to about 260. The fraction of 'G' cars, therefore, decreased from about one-half to about one-third. Available data (Appendix C) imply that airborne particulate matter would be reduced accordingly. When the residual contribution of the 'H' cars is taken into account (see Figure 4.2) the concentration of airborne particulate matter would have been reduced by about one-fourth (25 per cent) by the dilution effect of the addition of 'H' cars to the Yonge-University-Spadina fleet. This calculation assumes that the headway between trains remained unchanged, which is roughly the actual case.

7.3.5.5 Summary of Effects of Equipment Changes

The calculated approximate brake shoe emissions are compared in Table 7.2. The emissions are compared with those at the time of the 1976-77 measurements by means of the ratios given in column 3 of Table 7.2. These numbers indicate that the brake shoe emissions into the Yonge-University section by the current (1979) fleet (nearly all 'G' cars converted to Cobra brake shoes) are about 2.5 times lower than for the 1976-77 fleet operating on that portion of the system. Since brake shoe emissions account for at least one-half of suspended particulate in the subway, the suspended particulate levels at present should be reduced by about 30 per cent to 50 per cent relative to those measured in 1976-77. The uncertainty in this estimate arises from the lack of information about the relative contribution of wheel and rail wear to total suspended particulate loadings at the various TSP measuring sites. Even if brake shoe emissions were reduced to zero, this residual loading of iron dust from wheel and rail wear would remain.

On the same basis, the eventual TSP (or COH) levels produced by an 'all 'H' fleet would be about five times lower than the measured 1976-77 levels. This would bring TSP (or COH) levels on the Yonge-University(-Spadina) line down to the measured levels on the Bloor-Danforth line during the 1976-77 studies.

The recommended monitoring program will confirm the actual reductions in TSP (or COH) that have occurred.

7.3.5.6 Asbestos

Since the asbestos content of the Cobra and Anchor shoes is about the same, the expected reduction in asbestos concentrations for the 1979 conditions would be also about 50 per cent relative to 1976/78 conditions, that is, the same as the predicted TSP reduction. The further reduction to about 20 per cent of 1976/78 levels should accompany the phasing out of 'G' cars. The development of asbestos-free brake shoes would alleviate this portion of the emissions. Manufacturers have indicated some progress in this direction.

7.3.5.7 Lead

Since the Cobra shoe has at most one-fifth of the lead content (or less) of the Anchor shoe, the reduction in lead concentrations on the Yonge-University-Spadina line('G' cars) would be proportionally greater than the reductions in TSP and asbestos. The combined reduction in lead concentrations for the 1979 fleet (Y-U-S line) should be a factor of at least (0.5) x (0.2) = 0.1, corresponding to at least a 90 per cent reduction relative to 1976/77 levels.

This would bring the current average daily lead concentration on the Yonge-University-Spadina line down to essentially the same as that measured for the Bloor-Danforth line.

7.3.5.8 Other Constituents of TSP and Brake Shoe Dust

All components of brake shoe dust that contribute to TSP should be reduced by approximately the factors given in Table 7.2, taking into account the residual contribution of wheel and rail wear.

The fraction of TSP produced by wear processes other than brake shoe wear will remain.

TABLE 7.1

Summary of Platform Tests at Lawrence and Bay Stations

	Lawrence Station		Bay Station
	'G' Car Test (Apr.24-25)	'H' Car Test (May 1-2)	Average Weekday Values ('H' Cars Only)
TSP	1855 ug/m^3	746 ug/m^3	624 ug/m^3
Pb	63.1 ug/m^3	24.8 ug/m^3	15.9 ug/m^3
Fe	45.9%	56.8%	53.2%
C	6.1%	7.7%	9.5%

TABLE 7.2

Approximate Calculations of Effect of Equipment Changes on Brake Shoe Emissions on the Yonge-University Portion of the System

Equipment	Cumulative Per cent Reduction	Relative Brake Shoe Emissions
1976-77 fleet	-	1.0
Increased ratio of 'H' to 'G' Cars (1978 Y-U-S fleet)	25%	0.75
'G' Cars Converted (1979 Y-U-S fleet)	57%	0.4
All'H' fleet (1990, projected)	89%	0.1

APPENDIX A

1. SEQUENTIAL LISTING OF EVENTS
   SEPTEMBER 1976 to APRIL 1978

2. EXCERPTS FROM " SUBWAY ENVIRONMENTAL DESIGN HANDBOOK" (Volume I)

APPENDIX A

SEQUENTIAL LISTING OF EVENTS
SEPTEMBER 1976 to APRIL 1978 (TTC Engineering Department Log)

September 7, 1976	- MOE/MOL/TTC Working Group's first Meeting.
September 10, 1976	- MOE/TTC discussion on proposed measurement program.
September 10, 1976	- Subway field trip to obtain acoustical material wall samples.
September 14, 1976	- MOE/MOL/TTC Working Group Meeting.
September 16, 1976	- Four brake shoes (two Anchor, two Cobra) given to MOE for analyses.
September 23, 1976	- MOE/TTC surveyed stations to be tested and placement of a light scatter instrument at Queen's Park Station.
September 24, 1976	- Meeting at MOL to review personnel sampling devices. One was loaned for demonstrating to TTC personnel, and a tentative test plan was distributed.
October 1, 1976	- Discussions were held to review the test week October 18-22, 1976.
October 4, 1976	- Drawings of test locations delivered to MOE.
October 5, 1976	- MOE/TTC tour of all test locations to check power and installation accessibility.
October 6, 1976	- Internal TTC meeting to review test schedule.
October 7, 1976	- TTC Management/Union meeting to review tests and to bring Union employees up to date. Brief progress report submitted to group.
October 12, 1976	- Study progress report submitted to Commission. Toronto Star summarized report in October 13 edition.
October 15, 1976	- MOE/MOL/TTC Working Group Meeting.

October 18-22, 1976	- Thirteen structure locations measured with single or multiple pieces of MOE equipment. On-car tests conducted by MOE/MOL staff. Station collectors, janitors and track patrol fitted with MOL personnel sampling apparatus.
November 12, 1976	- TTC and MOE staff met Toronto Star reporter and photographer at Bay Station for coverage on tests. A newspaper article, without photographs, appeared in Saturday, November 13, edition.
November 30, 1976	- TTC/MOE telephone discussions re: acoustic wall material, brake shoes, and ORF analyses.
December 14, 1976	- MOE/MOL/TTC Working Group Meeting.
December 16, 1976	- Internal TTC meeting to review subway wall washing methods; wall washing test program to evaluate its effectiveness in eliminating dust/haze problem.
January 5, 1977	- Eight brake shoes, two of each of four types, delivered by the TTC to the Ontario Research Foundation for analyses. Included a lead-free brake shoe.
January 17, 1977	- CFTO-TV prepared film news report on study; shown on 6:30 p.m. and 11:00 p.m. newscasts.
February 4, 1977	- MOE/MOL/TTC Working Group Meeting.
February 4-22, 1977	- MOE instrumentation on loan to TTC set up at Queen's Park Station. Over one-week period, 10 complete wall-wash passes (walls, ceilings, floors) performed on both tracks.
February 23 - March 16, 1977	- Ongoing tests made by TTC using MOE test equipment. At Queen's Park location, station ventilating fans were turned on for 24-hour period. Equipment taken to Lawrence Station; similar wall-wash ventilating fan program conducted at that location.
March 17, 1977	- MOE/MOL/TTC Working Group Meeting.
April 6, 1977	- TTC/MOE meeting at MOE (Don Mills) office to discuss the ongoing tests and MOE instrumentation loan, which began on Friday, April 15.
April 15, 1977	- Installation of MOE measuring equipment at Bay Station for continuous monitoring on Bloor-Danforth Subway.

April 20, 1977	- Installation of MOE measuring equipment at Lawrence Station for Yonge Subway tests
April 20, 1977	- TTC Study Progress Report prepared for next Working Group meeting.
May 6, 1977	- MOE/MOL/TTC Working Group Meeting.
May 30, 1977	- Chronological list of brake shoe data assembled for Equipment Department for period September 10, 1976 to May 18, 1977.
June 24, 1977	- Update letter from TTC Equipment Department on brake shoe tests on Gloucester Subway Cars. 16'G' car brake shoe heads modified to accept Abex Tiger lead/asbestos-free shoes.
June 30, 1977	- MOE/MOL/TTC Working Group Meeting
August 2, 1977	- Two MOE Hi-Vol samplers loaned and delivered to Equipment Department, Greenwood, for power-load check prior to August 16 and 17 tests.
August 2, 1977	- Four brake shoes (two Abex, two Griffin lead/asbestos-free) delivered to ORF for analyses.
August 3, 1977	- Equipment & Engineering Department tests on MOE Hi-Vols for upcoming tests.
August 4, 1977	- Internal TTC letter from Safety to Head Office concerning air quality progress report.
August 5, 1977	- Internal TTC discussion on brake shoe wear mileage for Abex and Griffin shoes.
August 9, 1977	- Internal TTC letter from Equipment to Safety concerning lead-free brake shoes (i.e., stopping distances, second set for testing, G car replacements, etc.)
August 16&17, 1977	- On-car MOE tests on 'G' and 'H' cars on Yonge/University Subway line.
August 16, 1977	- Internal TTC data on test (Abex and Griffin) brake shoe weights before and after on-car tests.
August 18-22, 1977	- TTC/MOL telephone discussions to establish second TTC personnel TSP survey (no date established).

August 24, 1977	- TTC/MOL test to review TTC blood/lead tests.
August 25, 1977	- Tentative meeting schedule arranged (September 6 and 7). Tests to be done on both systems and stations Woodbine/College/Lawrence.
August 26 - September 1, 1977	- Arrangements for MOL/TTC Employee (TSP) survey.
September 6-7, 1977	- In-subway MOL employee sampling conducted on both subway lines and at three stations.
September 27, 1977	- TTC/MOE Abatement meeting to review all phases of subway air quality program.
October 5, 1977	- TTC/MOE discussion concerning ORF brake shoe lead/asbestos-free analyses.
October 7, 1977	- Internal TTC discussion about subway wall-wash vehicle for MOE Abatement personnel.
October 18, 1977	- Internal TTC discussion about on-going brake shoe tests with Cobra lead-free shoe.
November 2, 1977	- MOE/MOL/TTC Working Group Meeting. Final Report Sub-Committee formed of MOE/MOL/TTC staff.
November 2 & 22, 1977	- Review and discussion of TTC Workmen's Compensation Claims for respiratory problems. Files go back to 1963 with no claims listed.
November 9, 1977	- MOE Abatement Section participation on typical subway wall-wash night.
November 29, 1977	- Commission commited in principle to replacing all brake shoes with Cobra 392 lead-free (low-lead) shoe.
December 14, 1977	- MOL/TTC Medical Officer telephone discussion to arrange plans for TTC employee blood/lead survey.
December 14, 1977	- Brake shoe history memo prepared by TTC Equipment Department.
December 15, 1977	- MOE/MOL decision to determine exact quantities of iron in brake shoes. ORF to be informed to proceed.

December 15, 1977	- First meeting of MOE/MOL/TTC Final Report Sub-Committee. Final report format developed.
December 16, 1977	- Internal TTC meetings to discuss TTC employee blood/lead survey of approximately 40 long-subway-service employees from various job categories: drivers, guards, janitors, trackmen, collectors, etc.
December 20, 1977	- MOE informed TTC that ORF quantitative tests would not be completed until early 1978.
December 20, 1977	- Internal TTC discussion: Equipment Department to obtain percentages of asbestos content in brake shoes from brake shoe manufacturers.
December 28, 1977	- TTC Plant Department memo received indicating Safety and Security had received names of Plant Department employees re: blood/lead survey.
January 4, 1978	- Internal TTC meeting to review date for blood/lead survey Management/Union meeting; Commission report on study.
January 6, 1978	- Air Quality Progress Report prepared and issued internally.
January 13, 1978	- Management/Union meeting on blood/lead survey set for January 24, 1978.
January 16, 1978	- TTC received ORF brake shoe analyses results from MOE.
January 20, 1978	- TTC Equipment Department memo received indicating trains to use Cobra W392 brake shoes. Brake shoe history report received.
January 24, 1978	- Internal Management/Union Meeting held to bring subway dust committee up to date on subway air quality; study members informed of the up-coming employee blood/lead survey.
January 24, 1978	- Equipment Department letter received indicating brake shoe heads on 'G' cars to be modified as quickly as possible and, Corbra W392 brake shoes to be brought in as Anchor shoes phased out.

January 25, 1978	- Memo received indicating blood/lead survey questionnaire to be forwarded to employees and tests to be set up as soon as possible.
February 13, 1978	- COH air quality tests conducted before and after removal of fibreglass acoustic material on original Yonge Subway north of Wellesley Station. (Tests to evaluate dust effects with no acoustic material on wall.)
April 3, 1978	- TTC employees blood/lead level test conducted at Hillcrest Medical Center. Samples sent to Occupational Health Lab on Christie Street.
April 19, 1978	- Second meeting of Final Report Sub-Committee held at 880 Bay Street (MOE).

SUBWAY ENVIRONMENTAL DESIGN HANDBOOK

Volume I
Principles and Applications

2nd Edition

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2.2. Air Quality

Air-quality criteria are presented in this section to indicate practical limits on the quantity and nature of contaminants in the air affecting patrons and employees of rapid transit systems.

Clean air in a subway is defined as an atmosphere that contains concentrations of contaminants that are insufficient to impair the health, comfort, or vision of the patrons or employees, or to be aesthetically unpleasant to them. (Air quality criteria required to protect equipment and hardware are not presented in this section. Equipment should be designed for service in subways or, at the manufacturer's recommendation, should be isolated from the subway environment.)

Air quality in a subway depends on the amount of contaminants generated and made airborne in the system and the quality of ventilation air drawn into the subway. Patrons and employees may experience one or more of the following effects if air contaminants are present in sufficient concentrations:

Annoyance — For example, odors or haze.

Short-term incapacitation — For example, drowsiness induced by high level of carbon dioxide which disappears shortly after carbon dioxide level is restored to normal.

Cumulative long-term fibrosis or toxicity — For example, silicosis may result from prolonged exposures to small amounts of airborne silica dust.

For purposes of developing criteria, three general types of contaminants are considered: odorants, particulates,

and gases. When limits are being established on the contaminate concentrations to protect health, occupational standards govern. Although the general public is exposed to the subway environment, ambient air-quality standards, such as those promulgated under the Clean Air Act of 1970 by the Federal Environmental Protection Agency, do not apply.

To meet the limits on concentrations, a contaminant preferably should be controlled at its source and prevented from becoming airborne. Where this is not practicable, the concentration must be reduced by dilution of the contaminant with fresh ventilation air. Subway environmental engineers should arrange to supply subways with reliable sources of clean ventilation air from aboveground. Engineers must isolate subway systems and their air intakes from such sources of low-quality air as underground garages or bus loops, and they should be cautious when placing street-level ventilation openings near automotive exhausts.

Odorants

Any airborne gas or particle that can produce an odor sensation is an odorant. The human physiological reaction mechanism to odorants is not fully understood.

Individual reactions to odors vary greatly. Odors that are pleasant to some people are unpleasant to others, and the threshold at which different individuals can sense them varies widely. Usually, when several odorants are present, only the odor most prominent is detected because it masks the others.

General Odor Criterion. Because the description and quantification of odors are personal characteristics, the basic criterion for odor control requires exercise of judgment. The criterion requires that concentrations of odorants should not reach offensive levels. This, however, is not a workable criterion on which control strategy can be based. Odor-control strategies should aim at the reduction or elimination of either the sources of odorants or the concentrations of airborne odorants that can reach people.

Odorant Sources. In a subway, odors are derived primarily from people or putrefying organic matter. Tobacco smoke is produced by people, and body odors arise from people. Though smoking may be prohibited in a subway and thus eliminated as an odorant source, there is no practical way to reduce the odors caused by people. Odors from organic matter can be reduced by diligent maintenance and janitorial service in stations and tunnels to prevent accumulation of putrescible material. Architectural design should be such that waste-collection containers are readily available throughout stations and in subway cars, so that patrons can deposit putrescible materials in appropriate containers. Also, architectural design of stations should preclude areas, other than restrooms, in which persons can urinate or defecate. Areas where free moisture is allowed to stand are potential sources of odorants and should be eliminated from subways or be the object of intensive maintenance.

Odor Control by Ventilation. Once an odorant is airborne, the practical method for controlling its concentration is to dilute it with uncontaminated air, usually drawn from outdoors. For this purpose, a subway should be supplied with clean, odor-free, outdoor air. Consequently, fresh-air inlets should not be near sources of odorants, such as bus loops, automobile stops, and building vents.

Within a subway, areas that are potential sources of odor should be ventilated at a rate of at least four air changes per hour. Air from areas that are known sources of odors, such as food-vending areas, should be exhausted to prevent any odors from entering the subway environment. Restrooms should be ventilated at a rate of more than 12 air changes per hour.

To prevent accumulation of offensive human odors, fresh air should be supplied at a minimum rate of 5 cfm per person. Air-conditioning systems that have been in use in buses, passenger trains, and subway cars provide, under peak-load conditions, 5 to 10 cfm per person, which appears to be acceptable (Ref. 7).

Particulate Contaminants

Particulate contaminants of special concern to subway engineers are those generated within the subway. The intake of particles with street-level air can be avoided by locating fresh air intakes where the air is clean or, if this is impractical, by placing filters at intakes. These intake filters will remove large particulates, which can foul air-conditioning equipment and dirty the diffusers. But these filters will not appreciably alter the concentration of respirable particulates.

Particulate Sources. Particulate loading of subway air should be anticipated to be much greater than that of ordinary outdoor air. Under normal conditions, train

perations and patrons are the primary sources of irborne particles. These may be organic droplets from aporized and degraded lubricants; iron and iron oxide om iron brake shoes, wheels and rails; rubber from tires; sbestos from composition brake shoes; graphite from notor or collector brushes; skin scales and hair fibers; and ust from innumerable sources. Much of the dust from hese primary sources settles on underground surfaces and nay be subsequently re-entrained in the air. This re-ntrained dust is considered a secondary dust source. Both rimary and secondary sources contribute to the overall articulate loading of the air.

Reduced Visibility. Patrons become aware of reduced isibility when they cannot readily distinguish objects at he far end of a station. Therefore, the nuisance factor ssociated with reduced visibility is limited to short listances, say a station length. This distance may be even onger when considering the visibility requirements of the notorman.

The extinction of a light beam is an accurate method of neasuring reduced visibility. Coefficients of extinction for ransmitted light give the loss of light per unit of distance hat a beam of light travels. A coefficient of extinction maller than 0.002 per ft produces a visibility limit for lark objects at least 2,000 ft away but does not cause haze normally noticeable to patrons in stations up to 800 ft ong.

In a few tests performed for applications other than subways, an approximate correlation was developed between the extinction of light beams and mass concentrations of dust. (No visibility reduction measurements have been made in subway systems.) For particle sizes typically found in the atmosphere, a coefficient of extinction of 0.002 per ft would be produced by a dust concentration of 0.00087 grains per cu ft (2.0 mg per cu m). For subway-station application, the correlation between visibility and dust concentration is:

$$L = \frac{0.7}{C} \qquad (2.6)$$

where L = visible station length, ft,

C = dust concentration, grains per cu ft

(Note: 1 grain per cu ft = 2,288.1 mg per cu m)

A patron may become aware of airborne dust in subways even if the airborne dust concentration meets a light-extinction criterion. In the subdued lighting at the ends of a station, extremely low concentrations of airborne dust will be visible because the particles scatter light from the headlights of an approaching train. Such observations of dust cannot be prevented, because light scattering can be eliminated only by having no airborne dust, which is not practicable.

Gases. Subways are generally free of ingredients that form gaseous materials and reduce visibility. Nearly all such contaminants that are found in subway systems are brought in by ventilation air.

Particulate Control. Concentrations of airborne particles can be controlled by reducing them at sources or diluting them. There is, however, no practicable means of controlling many primary sources of particles. For secondary particulate sources (the re-entrainment of settled dust), some subway maintenance men routinely wash down their entire system, tunnels and stations, with high-pressure hoses and others use a vacuum train. But, usually, control of particulate concentration is accomplished by using large amounts of outdoor air to dilute the subway air.

Concentrations of airborne particles can be estimated if the following are known: Ventilation rates that are determined by the methods given in Sec 3.1 and from the sum of the amount of material released to the air in the subway and the amount of particulates brought in by outdoor air. One subway dust survey revealed that dust concentration under the platform averaged about 0.39 grains per 1,000 cu ft (Ref. 8). The Clean Air Act of 1970, enforced by the U. S. Environmental Protection Agency, is aimed at reducing particulate loading in the atmosphere to an annual geometric mean of less than 60 μg per cu m (0.026 grains per 1,000 cu ft). Therefore, subway designers can assume that average ventilation air will be more than 10 times cleaner than that required for a station.

Limits on Airborne Particles in Subways. Industrial hygienists have long recognized that the effect of air contaminants are often time dependent. Relatively high concentrations for short periods can be tolerated, but long exposures to low levels may be physically damaging. Patrons, because of their transient, short-term exposures to a subway environment, can tolerate much higher concentrations of airborne contaminants than rapid transit employees, who may spend 40 hours or more each week in the subway. Particulate limits in rapid transit systems consequently are governed by the potential effects on the system workers.

Occupational exposures of industrial employees in the United States are limited by the Federal Regulations of

the Occupational Safety and Health Administration, Department of Labor (OSHA) (Ref. 9). The applicable national consensus standard for such occupational exposures is the Threshold Limit Values of the American Conference of Governmental Industrial Hygienists (ACGIH). Although some subway systems may be exempt from OSHA, and since the ACGIH has no enforcement powers, the subway must be designed to prevent adverse effects on subway employees and patrons. Therefore, concentrations of any airborne contaminant should not exceed those most recently established by OSHA regulations or those recommended by ACGIH. The values should be subject to the interpretations, limitations and qualifications set by OSHA and ACGIH, respectively.

Limits set by OSHA and ACGIH for those contaminants that might be expected to occur in subway environments are given in Table 2.8.

Table 2.8. Representative Limits for Particulate Contaminants Generated in Subway Environment

	OSHA Exposure Limit, mg per cu m	ACGIH Threshold Limit Values, *TLV* mg per cu m
Iron-oxide Fume	10	10
Inert or Nuisance Dusts; Respirable Fraction	5	
Total	15	10

The ACGIH defines threshold limit values *TLV* as "The values for airborne toxic materials which are to be used as guides in the control of health hazards and represent time weighted concentrations to which nearly all workers may be exposed 8 hours per day over extended periods of time without adverse effects" (Ref. 10). ACGIH discusses dust further:

"*Nuisance Dusts.* In contrast to fibrogenic dusts which cause scar tissue to be formed in lungs when inhaled in excessive amounts, so-called 'nuisance' dusts have a long history of little adverse effect on lungs and do not produce significant organic disease or toxic effect when exposures are kept under reasonable control. The nuisance dusts have also been called (biologically) 'inert' dusts, but the latter term is inappropriate to the extent that there is no dust which does not evoke some cellular response in the lung when inhaled in sufficient amounts. However, the lung-tissue reaction caused by inhalation of nuisance dusts has the following characteristics: 1) The architecture of the air spaces remains intact. 2) Collagen (scar tissue) is not formed to a significant extent. 3) The tissue reaction is potentially reversible.

"...A threshold limit of 10 mg per cu m, or 30 million particles per cu ft, of total dust less than one percent SiO_2, whichever is less, is recommended for substances in these categories for which no specific threshold limits have been assigned. This limit, for a normal workday, does not apply to brief exposures at higher concentrations. Neither does it apply to those substances which may cause physiologic impairment at lower concentrations but for which a threshold limit has not yet been adopted."

Some "inert" particulates, when toxic impurities are not present, for example, quartz less than one percent, are given in Table 2.9 (Ref. 10).

Table 2.9. Contents of Some Inert Dusts (In the Absence of Toxic Materials)

Calcium Carbonate	Limestone
Cellulose (Paper Fiber)	Magnesite
Portland Cement	Marble
Corundum (Al_2O_3)	Pentaerythritol
Emery	Plaster of Paris
Glycerine Mist	Rouge
Graphite (Synthetic)	Silicon Carbide
Gypsum	Starch
Vegetable Oil Mists	Sucrose
(Except Castor, Cashew Nut, or Similar Irritant Oils)	Tin Oxide
Kaolin	Titanium Dioxide

OSHA defines "asbestos fibers" as meaning asbestos fibers longer than 5 micrometers (microns). Concentrations of

airborne asbestos in any rapid transit structure or vehicle should, after July 1, 1976, conform to the following OSHA standard: "The 8-hour time-weighted average airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed two fibers, longer than 5 micrometers, per cubic centimeter of air...." (Ref. 9).

Gaseous Contaminants

If present in sufficient concentrations, gaseous contaminants have annoying, incapacitating or toxic effects. Such contaminants may be brought into a subway with outdoor air or may be generated in the subway.

Gaseous contaminants that may be present in outdoor air and drawn into a subway with ventilation air include sulfur oxides, nitrogen oxides, hydrocarbons, ozone, carbon monoxide, carbon dioxide, hydrogen sulfide, and organic products of partial combustion called carbonyls. Subway environmental engineers should locate intakes where contaminants are not likely to be present.

Only two gaseous contaminants are normally generated within subways: carbon dioxide from passenger respiration and ozone from electrical propulsion machinery.

Accumulation of carbon dioxide is of special concern. A symptom of high carbon-dioxide concentration is drowsiness. While always present in outdoor air to some extent, particularly in areas with heavy concentrations of motor vehicles, carbon dioxide is produced by patrons in trains and stations at a rate that can readily produce concentrations of 9,000 mg per cu m. The only practicable method for controlling carbon-dioxide concentrations is to dilute them with fresh air.

Ozone results from operation of high-voltage electrical equipment in subways. Ozone, although a very active element, is usually not objectionable because concentrations are low. As with carbon dioxide, the only practicable means of reducing ozone concentration is to dilute it with fresh air.

Maximum allowable concentrations of gaseous contaminants recommended by the American Conference of Governmental Industrial Hygienists (Ref. 10) and OSHA (Ref. 9) are given in Table 2.10. A value for carbon monoxide has also been included in case a vent shaft has to be located near automotive exhausts.

Table 2.10. Representative Threshold Limits for Gaseous Contaminants in Subway Environment, mg per cu m

Carbon Dioxide	9,000
Carbon Monoxide	55
Ozone	0.2

To keep concentrations below those in the table, the recommended minimum ventilation with outdoor air is 7.5 cfm per person in stations and tunnels and 5 cfm per person in trains. Such inflow may be accomplished by diffusion and mixing outdoor air with the tunnel and station air.

Institute for Rapid Transit "Specification for Rapid Transit Cars" (Ref. 7) calls for a minimum of 6.5 cfm of fresh air per passenger. This is consistent with the above criteria. The IRT specifications consider tunnel air as fresh, whereas these criteria base minimum supply air on outdoor air.

APPENDIX B

RELATIONSHIP BETWEEN TSP AND COH

APPENDIX B

RELATIONSHIP BETWEEN TSP AND COH

There is no standard relationship between COH and TSP. (The COH sampler measures transmitted light; therefore, the colour and darkness of particulate affects COH value.) The results of the subway survey show very high levels of iron and carbon (both dark particulates), which vary between stations. The relationship between COH and TSP, therefore, may differ and must be calibrated for each individual subway station involved.

Hi-Vol air samplers were used to determine total suspended particulate (TSP) concentrations over 24 hours in the Queen's Park, Lawrence, and Bay subway stations. These data are presented in Tables Bl through B3. Concurrently with the Hi-Vol program, the coefficient of haze was determined for hourly periods, then averaged over the same period as the Hi-Vol samples. The COH values are compared to the TSP in tables B4 through B6. A linear regression analysis was performed on the data for each station and the TSP-COH relationships are plotted in figure B1.

The TSP-COH relationship in Bay station can be represented by the linear equation TSP = 57.23 (COH) + 67.77 with a correlation coefficient of 0.82. Similarly, the TSP-COH relationship in Lawrence station can be represented by TSP = 144.48 (COH) - 281.44 with a correlation coefficient of 0.87. Although those two stations have a relatively high correlation coefficient between COH and TSP, no strong relationship between TSP and COH could be found from the data collected at Queen's Park station, as indicated by the low correlation coefficient (0.37). For this reason the Queen's Park data were not plotted.

TABLE B1

HI-VOL ANALYSIS: QUEEN'S PARK STATION

FILTER NUMBER	EXPOSURE DATE (1977)	AIR FLOW (m^3)	TARE WT. (g)	LOAD WT. (g)	TSP ($\mu g/m^3$)
44032 103	Feb. 8 - 1400 Feb. 9 - 1400	1631	3.4541	4.8700	868.1
35038 037	Feb. 9 - 1400 Feb. 10 - 1400	1616	3.3602	4.7577	864.8
35038 038	Feb. 10 - 1400 Feb. 11 - 1400	1614	3.3667	4.7000	826.1
35038 039	Feb. 14 - 1020 Feb. 15 - 1020	1614	3.3469	4.6993	837.9
35038 040	Feb. 15 - 1015 Feb. 16 - 1015	1631	3.3512	4.5872	757.8
35038 041	Feb. 16 - 1015 Feb. 17 - 1015	1614	3.3454	4.5495	746.0
35038 042	Feb. 17 Feb. 18	1614	3.3562	4.7417	858.4
35038 043	Feb. 21 - 1030 Feb. 22 - 1030	1648	3.3580	4.8967	933.7

TABLE B2

HI-VOL ANALYSIS: LAWRENCE STATION

FILTER NUMBER	EXPOSURE DATE (1977)	AIR FLOW (m^3)	TARE WT. (g)	LOAD WT. (g)	TSP ($\mu g/m^3$)
44031 101	Apr. 21 - 1245 Apr. 22 - 1115	1699	3.7651	6.4046	1554
44031 102	Apr. 24 - 0530 Apr. 25 - 0245	1347	3.7452	6.2442	1855
33029 124	Apr. 25 - 1100 Apr. 26 - 1015	1531	3.6670	6.1719	1505
33029 125	Apr. 26 - 1100 Apr. 27 - 0900	1473	3.8526	6.4397	1756
33029 127	Apr. 27 - 1115 Apr. 28 - 1100	1503	3.8614	6.6500	1855
33029 131	Apr. 28 - 1500 Apr. 29 - 1500	1600	3.8533	6.4831	1644
33029 133	May 1 - 0915 May 2 - 1115	1955	3.8419	5.3012	746
33029 136	May 2 - 1115 May 3 - 1045	1601	3.8602	6.5315	1669
33029 138	May 3 - 1100 May 4 - 1100	1590	3.8648	5.9541	1314
33029 139	May 4 - 1100 May 5 - 1100	1706	3.8558	6.1024	1317

TABLE B3

HI-VOL ANALYSIS: BAY STATION

FILTER NUMBER	EXPOSURE DATE (1977)	AIR FLOW (m^3)	TARE WT. (g)	LOAD WT. (g)	TSP ($\mu g/m^3$)
44031 098	Apr. 19 - 1015 Apr. 20 - 1000	1642	3.7949	4.8986	672
44031 099	Apr. 20 - 1015 Apr. 21 - 0945	1609	3.7829	4.9200	707
44031 100	Apr. 21 - 1015 Apr. 22 - 1015	1641	3.7339	4.8286	667
33029 126	Apr. 26 - 1115 Apr. 27 - 1100	1644	3.8758	4.9200	635
33029 128	Apr. 27 - 1115 Apr. 28 - 1115	1676	3.8835	4.8870	599
33029 130	Apr. 28 - 1130 Apr. 29 - 1130	1668	3.8662	4.8224	573
33029 135	May 2 - 1030 May 3 - 1030	1662	3.8568	4.7565	541
33029 137	May 3 - 1030 May 4 - 1015	1650	3.8408	4.9022	643
33029 139	May 4 - 1030 May 5 - 0915	1575	3.8345	4.7453	578

TABLE B4

TSP VS. COH RELATIONSHIP: QUEEN'S PARK STATION

DATE (1977)	TIME	AVERAGE COH OVER SAMPLING PERIOD	TOTAL SUSPENDED PARTICULATE ($\mu g/m^3$)
Feb. 8 Feb. 9	1400 1400	10.92	868.1
Feb. 9 Feb. 10	1400 1400	10.1	*864.8
Feb. 10 Feb. 11	1400 1400	9.9	826.1
Feb. 14 Feb. 15	1020 1020	8.4	837.9
Feb. 15 Feb. 16	1015 1015	8.4	*757.8
Feb. 16 Feb. 17	1015 1015	NA	*746.0
Feb. 17 Feb. 18	1000 1000	9.2	858.4
Feb. 21 Feb. 22	1030 1030	9.3	933.7

* After Wall Washing

TABLE B5

TSP VS. COH RELATIONSHIP: LAWRENCE STATION

DATE (1977)	TIME	AVERAGE COH OVER SAMPLING PERIOD	TOTAL SUSPENDED PARTICULATE ($\mu g/m^3$)
Apr. 21 Apr. 22	1245 1115	10.65	1554 *
Apr. 24 Apr. 25	0530 0245	13.65	1855 *
Apr. 25 Apr. 26	1100 1015	12.70	1505
Apr. 26 Apr. 27	1100 0900	14.16	1756
Apr. 27 Apr. 28	1115 1100	14.35	1855
Apr. 28 Apr. 29	1500 1500	14.04	1644
May 1 May 2	0915 1115	7.98	746 **
May 2 May 3	1115 1045	12.94	1669
May 3 May 4	1100 1100	13.15	1314 *
May 4 May 5	1100 1100	11.17	1317

TSP = 144.48(COH) - 281.44 . Correlation Coefficient = 0.87

* 'G' Car Test
** 'H' Car Test

TABLE B6

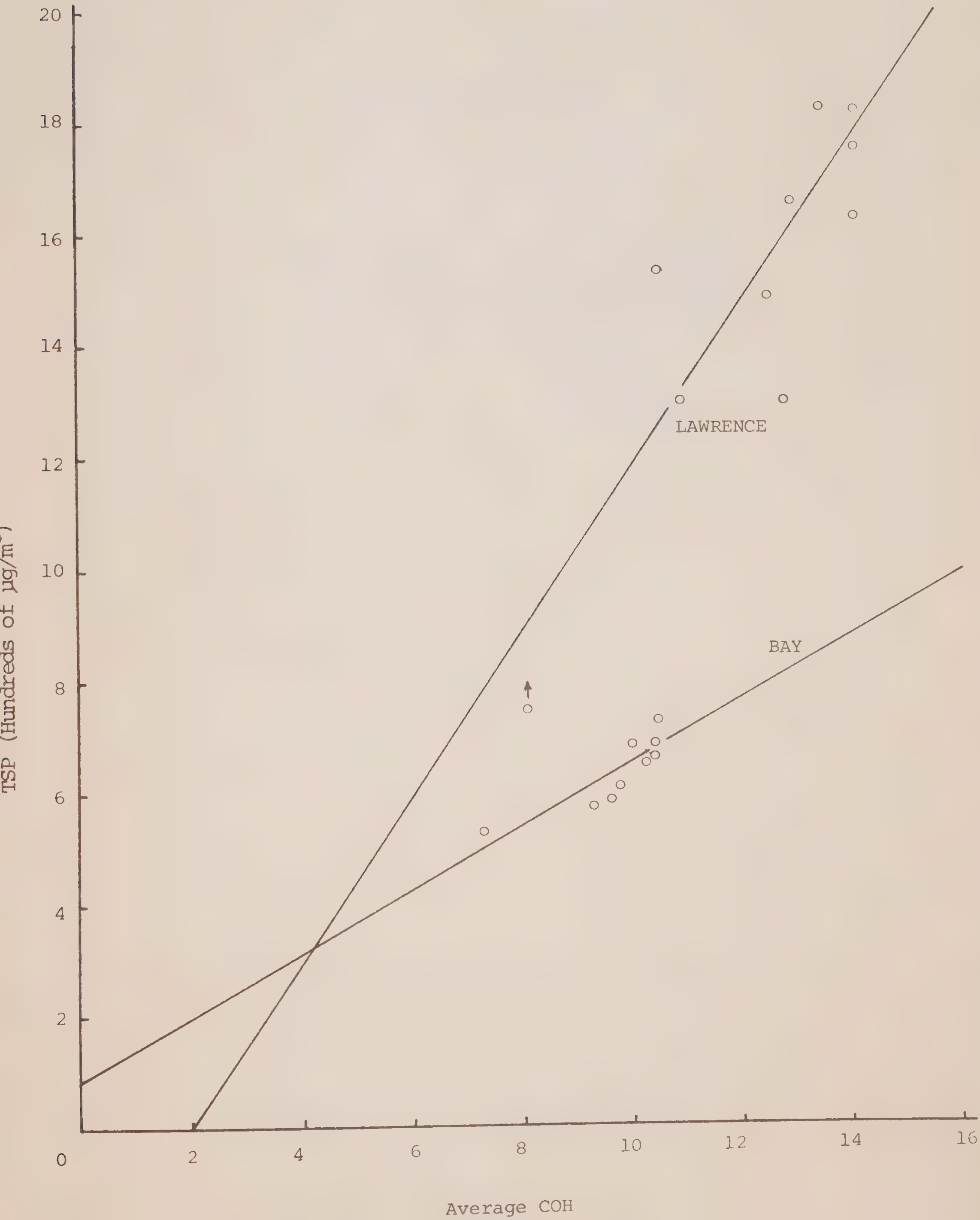
TSP VS. COH RELATIONSHIP: BAY STATION

DATE (1977)	TIME	AVERAGE COH OVER SAMPLING PERIOD	TOTAL SUSPENDED PARTICULATE ($\mu g/m^3$)
Apr. 19 Apr. 20	1015 1000	10.31	672
Apr. 20 Apr. 21	1015 0945	10.37	707
Apr. 21 Apr. 22	1015 1015	9.89	667
Apr. 26 Apr. 27	1115 1100	10.18	635
Apr. 27 Apr. 28	1115 1115	9.69	599
Apr. 28 Apr. 29	1130 1130	9.40	573
May 2 May 3	1030 1030	7.82	541
May 3 May 4	1030 1015	10.19	643
May 4 May 5	1030 0915	9.60	578

FIGURE B1

Total Suspended Particulate Versus COH Averaged Over 24 Hours

for Bay and Lawrence Stations



APPENDIX C

RELATIONSHIP BETWEEN FREQUENCY OF OPERATION AND COH

APPENDIX C

RELATIONSHIP BETWEEN FREQUENCY OF OPERATION AND COH

Measurements of COH levels in Bay and Lawrence stations were related to the type and frequency of trains serving these stations. Table C1 presents the operation schedule for both the Bloor-Danforth and Yonge-University lines. (From Table C1 were developed Tables 3.3 and 3.4, which list the frequencies of 'G' and 'H' trains passing the Lawrence and Bay stations. The COH values are averaged over the TTC schedule time periods (i.e., AM RUSH, DAY NORMAL etc.) and presented in Tables 4.6 and 4.7. The relationship between COH and frequency of operation was determined by simple linear regression analysis at Bay station and multiple linear regression at Lawrence, as both 'G' and 'H' cars serve this line. At Bay station the relationship equation is COH = 0.06 (H) + 4.4 with an "r" value of 0.84. The COH-frequency of operation relationship at Lawrence is COH = 0.11 (G) + 0.034 (H) - 5.5 with a correlation coefficient of 0.85. The variables 'G' and 'H' in both equations represent the frequency (in cars/hr) of cars passing through the station.

Table C3 shows estimated COH values for Lawrence station (based on the equation derived in regression analysis). Calculations of the COH value were performed for each period defined in the subway schedule (Table C1) comparing the exclusive use of 'G' cars and 'H' cars to the typical schedule. The equations predict that the use of Gloucester equipment exclusively would lead to an increase in COH of 40 per cent over the day while the use of 'H' cars exclusively would show a decrease in COH of 37 per cent. This finding relates closely to the measured values of COH during the Sunday car tests (Table 4.5).

TABLE C1

Subway Service Operation Schedule

Date	Period	Bloor	Yonge - University G	Yonge - University H
Thur. Apr. 21	AM Rush	29 x 6	14 x 8 cars	18 x 6 cars
	Day Normal	16 x 6	9 x 8	11 x 6
	PM Rush	29 x 6	14 x 8	18 x 6
	Early Evg.	15 x 6	9 x 8	11 x 6
	Late Evg.	15 x 4	7 x 8	5 x 6
Fri. Apr. 22	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	10 x 8	10 x 6
	PM Rush	29 x 6	14 x 8	18 x 6
	Early Evg.	15 x 6	10 x 8	10 x 6
	Late Evg.	15 x 6	9 x 8	3 x 6
Sat. Apr. 23	Day Normal	16 x 6	12 x 8	8 x 6
	Late Evg.	15 x 6	10 x 8	2 x 6
Sun. Apr. 24	All Day	15 x 4	12 x 8	-
Mon. Apr. 25	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	9 x 8	11 x 6
	PM Rush	29 x 6	14 x 8	18 x 6
	Early Evg.	15 x 6	13 x 6 + (1 x 8)	6 x 4
	Late Evg.	15 x 4	6 x 6	6 x 4
Tue. Apr. 26	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	9 x 8	11 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	15 x 6 + (1 x 8)	4 x 4
	Late Evg.	15 x 4	8 x 6	4 x 4
Wed. Apr. 27	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	9 x 8	11 x 6
	PM Rush	29 x 6	14 x 8	18 x 6
	Early Evg.	15 x 6	16 x 6	4 x 4
	Late Evg.	15 x 6	8 x 6	4 x 4
Thur. Apr. 28	AM Rush	29 x 6	15 x 8	17 x 6
	Day Normal	16 x 6	9 x 8	11 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	8 x 8	12 x 6
	Late Evg.	15 x 4	5 x 8	7 x 6
Fri. Apr. 29	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	6 x 8	14 x 6
	PM Rush	29 x 6	14 x 8	18 x 6
	Early Evg.	15 x 6	4 x 8	16 x 6
	Late Evg.	15 x 4	1 x 8	11 x 6
Sat. Apr. 30	Day Normal	16 x 6	9 x 8	11 x 6
	Late Evg.	15 x 6	7 x 8	5 x 6

(continued)

Date	Period	Bloor (H only)	Yonge - University G	Yonge - University H
Sun. May 1	All Day	15 x 4	-	12 x 6
Mon. May 2	AM Rush	29 x 6	15 x 8	17 x 6
	Day Normal	16 x 6	7 x 8	13 x 6
	PM Rush	28 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	12 x 6 + (2 x 8)	6 x 4
	Late Evg.	15 x 4	6 x 6	6 x 4
Tues. May 3	AM Rush	29 x 6	15 x 8	17 x 6
	Day Normal	16 x 6	10 x 8	10 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	17 x 6	3 x 4
	Late Evg.	15 x 4	9 x 6	3 x 4
Wed. May 4	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	8 x 8	12 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	14 x 6 + (1 x 8)	5 x 4
	Late Evg.	15 x 4	7 x 6	5 x 4
Thur. May 5	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	9 x 8	11 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	10 x 8	10 x 6
	Late Evg.	15 x 4	9 x 8	3 x 6
Fri. May 6	AM Rush	29 x 6	15 x 8	17 x 6
	Day Normal	16 x 6	9 x 8	11 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	9 x 8	11 x 6
	Late Evg.	15 x 4	8 x 8	4 x 6
Sat. May 7	Day Normal	16 x 6	12 x 8	8 x 6
	Late Evg.	15 x 6	9 x 8	3 x 6
Sun. May 8	All Day	15 x 4	8 x 8	4 x 6
Mon. May 9	AM Rush	29 x 6	15 x 8	17 x 6
	Day Normal	16 x 6	10 x 8	10 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	17 x 6 + (1 x 8)	2 x 4
	Late Evg.	15 x 4	10 x 6	2 x 4
Tues. May 10	AM Rush	29 x 6	14 x 8	18 x 6
	Day Normal	16 x 6	8 x 8	12 x 6
	PM Rush	29 x 6	15 x 8	17 x 6
	Early Evg.	15 x 6	12 x 6 + (2 x 8)	6 x 4
	Late Evg.	15 x 4	7 x 6	5 x 4

NOTE: No. of trains turned back at Eglinton

32 During AM Rush
9 During PM Rush

TABLE C2

SUMMARY OF COH / OPERATION FREQUENCY CORRELATION

	Bay	Lawrence
'G' Coefficient	-	0.1094
'H' Coefficient	0.05852	0.0353
INTERCEPT	4.3512	5.48212
Corr. Coefficient	0.844	0.847

TABLE C3

COH Level Estimations Based on Correlation Equation for Lawrence Station

COH = 0.1094 [G] + 0.0353 [H] + 5.48

AM RUSH*	YONGE SCHEDULE	FREQUENCY	COH	% CHANGE ***
Typical Schedule	14 x 8 'G' 18 x 6 'H'	49 cars/hr 47.3 cars/hr	12.1	0.0%
G Cars Only	32 x 8 'G'	112 cars/hr	17.73	+47%
H Cars Only	32 x 6 'H'	84 cars/hr	8.45	-30%
Day Normal & Early Evg.				
Typical Schedule	9 x 8 'G' 11 x 6 'H'	63.1 cars/hr 57.9 cars/hr	14.43	0.0%
G Cars Only	20 x 8 'G'	140.35 cars/hr	20.84	+44%
H Cars Only	20 x 6 'H'	105.3 cars/hr	9.20	-36%
PM RUSH**				
Typical Schedule	15 x 8 'G' 18 x 6 'H'	95.62 cars/hr 81.28 cars/hr	18.81	0.0%
'G' Cars Only	32 x 8 'G'	204 cars/hr	27.8	+48%
'H' Cars Only	32 x 6 'H'	153 cars/hr	10.9	-42%
Evening(Late)				
Typical Schedule	8 x 6 'G' 4 x 4 'H'	53.9 cars/hr 18.0 cars/hr	12.0	0.0%
'G' Cars Only	12 x 6 'G'	80.9 cars/hr	14.33	+19%
'H' Cars Only	12 x 4 'H'	53.9 cars/hr	7.40	-38%

* Frequency considers 32 trains being turned back at Eglinton

** Frequency considers 9 trains being turned back at Eglinton

*** From COH for typical schedule

Average Increase if only 'G' cars used : 39.5%

Average Decrease if only 'H' cars used : 36.5%

APPENDIX D

CALCULATION OF BLOOD LEAD LEVELS

APPENDIX D

I. Calculation of Absorption of Lead into Blood from Ambient Air, Food, and Water

Table D.1: Air to Blood Fraction and Absorption into Blood vs.Particle Size

Aerodynamic Diameter of Spheres (microns)	Air to Blood Fraction	Absorption of Lead in Blood (ug/day)
0.01	0.31	12.4
0.06	0.20	8.0
0.20	0.09	3.6
0.60	0.07	2.8
1.0	0.09	3.6
2.0	0.20	8.0
3.0	0.23	9.2
4.0	0.24	9.6
6.0	0.23	9.2
10.0	0.19	7.6

Reference: "The metabolism of Compounds of Plutonium and other Actinides". Task Group of Committee 2 of the ICRP.

Based on values of absorption from Table 1, 12.4 ug is calculated to be the most, and 2.8 ug the least, amount absorbed. Absorption of lead into blood of persons exposed to usual levels from ambient air concentrations of lead lies, therefore, between 2.8 ug/day and 12.4 ug/day, with 16 ug/day from food and water.

That is,

16 ug + 2.8 ug = 18.8 ug/day

and 16 ug + 12.4 ug = 28.4 ug/day.

II. Calculation of Absorption of Lead into Blood from Subway Air

The average air concentration of lead on the north/south line of the subway system (based on data collected in October 1976) was calculated to be 56. ug/m^3. Based on the particle size distribution found at Queen's Park Station, the particle size distribution of the average concentration of lead was found to be as follows:

Table D.2 Lead Particle Size Distribution

Aerodynamic Particle Size Range (microns)	Lead Concentration (ug/m^3)
7.0	13.
3.3 - 7.0	19.
2.0 - 3.3	12.
1.1 - 2.0	6.
1.1	6.

It is assumed for the following calculation that a person breathes subway air for 24 hours each day, 7 days a week, with an inspired volume of air of 20 m^3/day and a Tidal Volume of 750 cm^3.

The lung deposition model*, graphically represented in Figure 2, and the Class W excretion model (see Table 1) were used to calculate that the excretion rate from the respiratory tract to blood was 152 ug lead/day and that the excretion rate from the respiratory tract to the gastro-intestinal tract was 836 ug/lead/day.

If 0.1 is the fraction of lead crossing to blood from the gastro-intestinal tract, the intake rate to blood would be:

152 + 84 = 236 ug lead/day (over 24 hours).

For 2 hours/day, 5 days/week with a breathing rate of 1.25 m^3/hour, the absorption into blood resulting from exposure on the subway would be:

---

*"Deposition and Retention for Internal Dosimetry of the Human Respiratory Tract", Task Group on Lung Dynamics. Health Physics 12, 173-207 (1966).

$$\frac{5}{7} \times \frac{2\text{hr.}}{\text{day}} \times \frac{1.25\text{m}^3}{\text{hr.}} \times \frac{236\ \text{ug/day}}{20\ \text{m}^3/\text{day}} = 21.1\ \text{ug/day}$$

III. Estimated Absorption of Lead into Blood from Subway Air, Ambient Air and Food and Water

Absorption of lead into blood for a person who breathes 1.25 m^3/hr. and is exposed 2 hours/day, 5 days/week to air having a concentration of 2 ug lead/m^3 lies between

$$\frac{2.8\text{ug}}{\text{day}} \times \frac{2\ \text{hrs/day} \times 1.25\text{m}^3/\text{hr.}}{20\ \text{m}^3/\text{day}} \times \frac{5}{7} = 0.25\ \text{ug/day}$$

and

$$\frac{12.4\text{ug}}{\text{day}} \times \frac{2\ \text{hrs. day} \times 1.25\text{m}^3/\text{hr.}}{20\ \text{m}^3/\text{day}} \times \frac{5}{7} = 1.1\ \text{ug/day}$$

Based on all these calculations, the absorption of lead into blood of persons using the subway two hours/day otherwise lies between

18.8 ug/day + 21.1 ug/day - 0.25 ug/day = 39.75 ug/day (a)

and 28.4 ug/day + 21.1 ug/day - 1.1 ug/day = 48.4 ug/day (b)

Based on the model in Figure 1, the following concentrations of lead in blood can be calculated for various periods of exposure as follows:

where 'x' is the equilibrum blood burden in terms of daily intakes to blood, and 'y' is the blood volume in millilitres and F.E. is the Fractional Equilibrum,

$$100\ \frac{ax}{y} \times \text{F.E.} \quad \text{to} \quad 100\ \frac{bx}{y} \times \text{F.E.}$$

Table D.3: Comparison of Concentration of Lead in Blood for Persons to Usual Levels and Persons Using the Subway after Various Exposure Periods

Exposure Period (y)	Fractional Equilibrium	Lead Levels in Blood (ug/100 ml) Non-Subway users	Subway users
1	0.37	7 - 10	14 - 17
2	0.53	10 - 14	20 - 24
5	0.69	12 - 19	26 - 32
10	0.78	14 - 21	29 - 36
15	0.84	15 - 23	32 - 39
25	0.88	16 - 24	33 - 41
75	0.98	18 - 27	37 - 45
Equilibrium	1.00	18 - 27	38 - 46

The model described above was also used to calculate the various combinations of amounts of lead in food and water and air concentrations of lead which would result in a given lead concentration in blood after a given number of years of exposure. Since the amount of lead absorbed into blood from inhaled particles depends upon the size of the particles, the calculations were done using the minimum (0.07) and maximum (0.31) values of the air to blood fractions for inhaled lead. Figure 3(a) shows the various combinations of lead in food and water and lead concentration in air that would produce 15 ug of lead per 100 ml. of blood after 10 or 25 years of exposure. Figure 3(b) shows the various combinations of exposure that would produce 30 ug of lead per 100 ml. of blood after 10 or 25 years.

FIGURE D1. LEAD RETAINED IN BLOOD

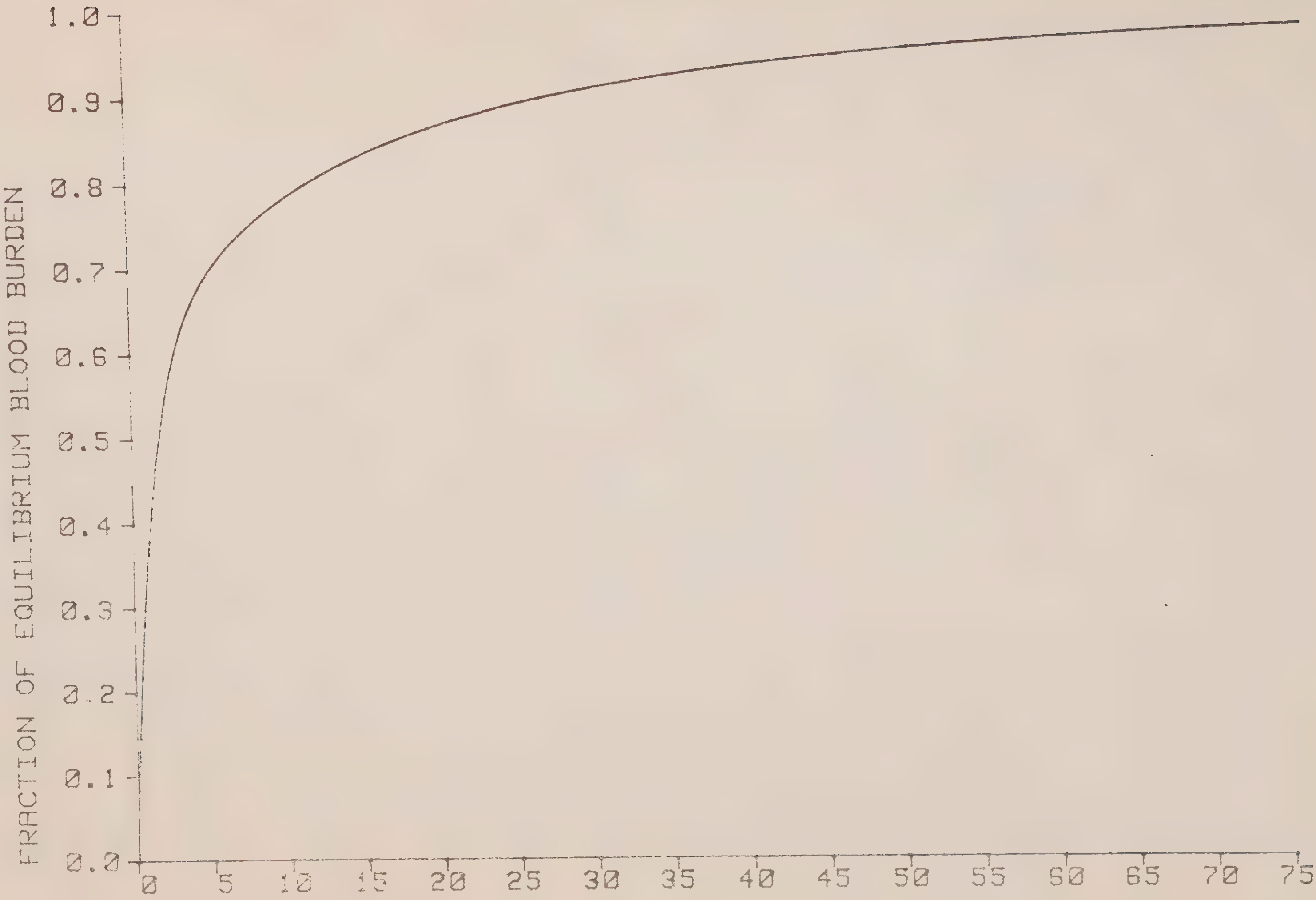
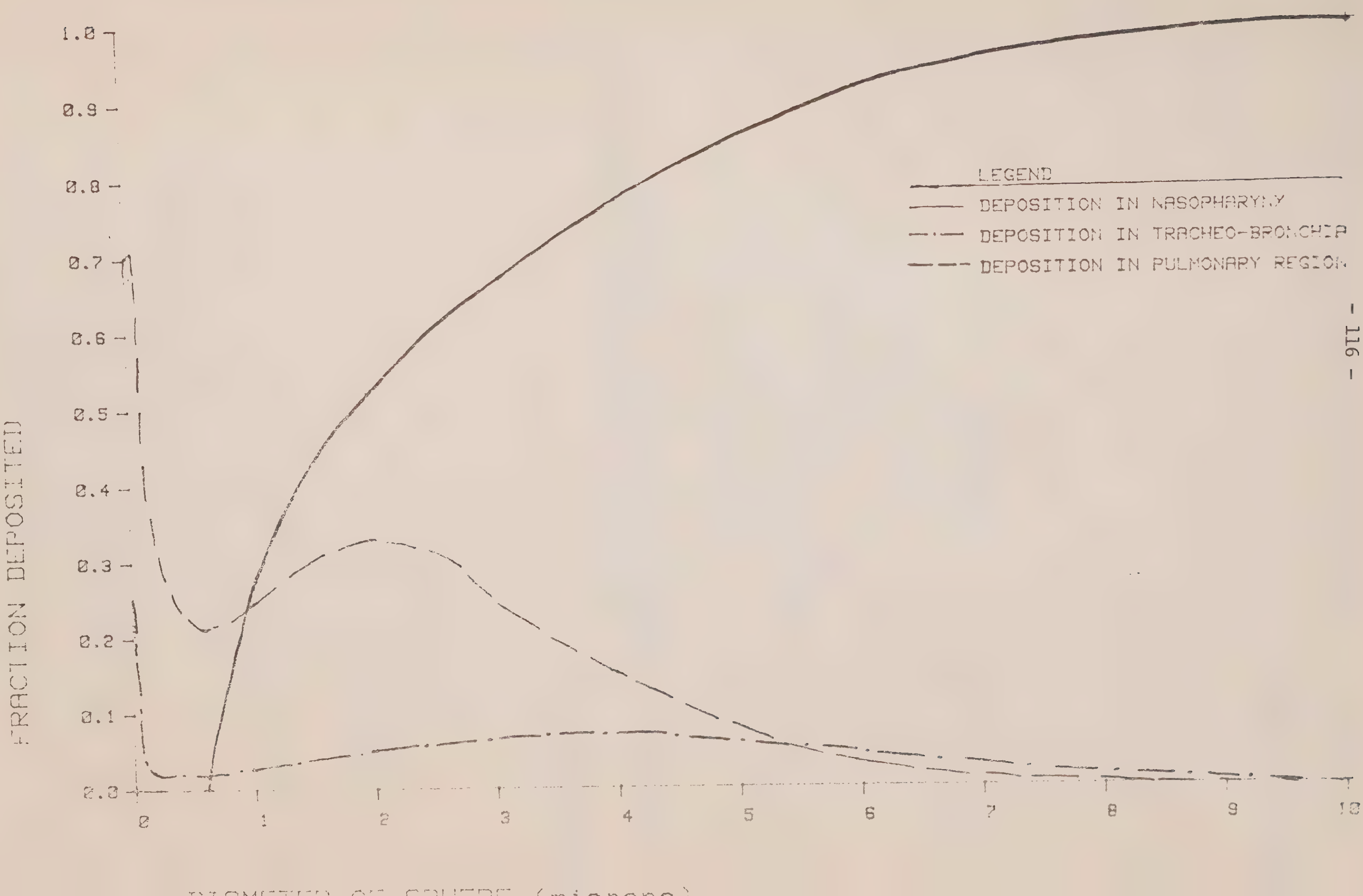
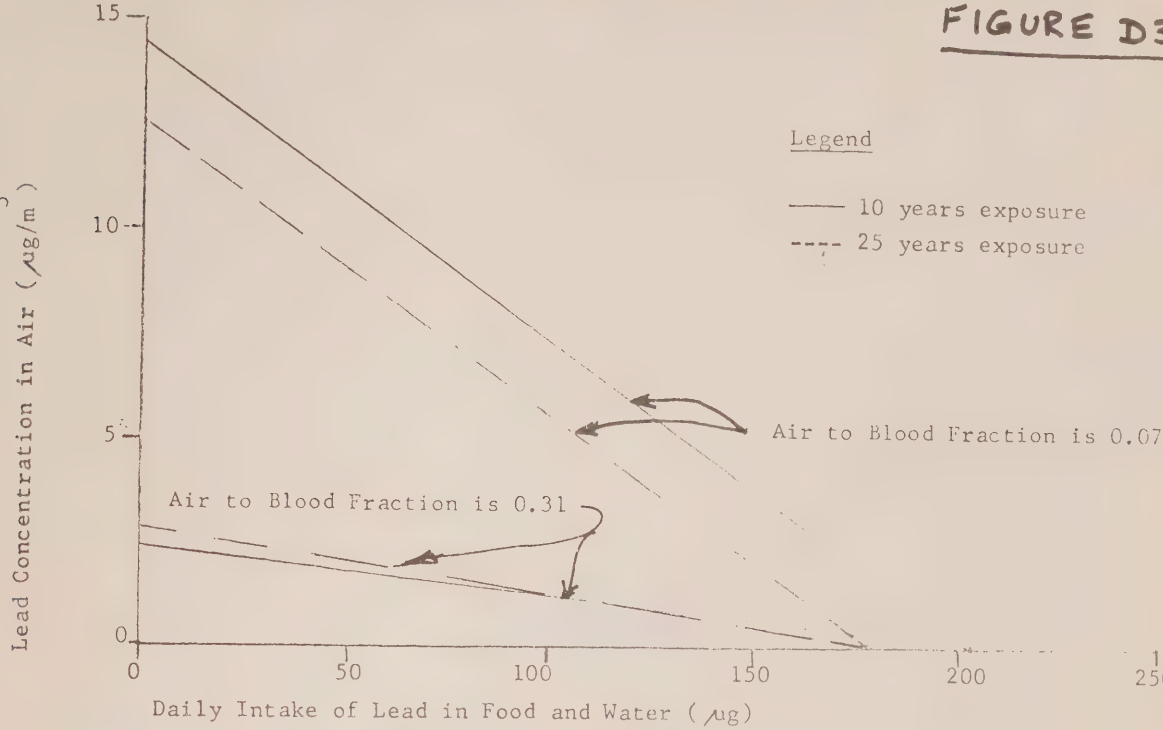


FIGURE D2. DEPOSITION OF UNIT DENSITY SPHERES



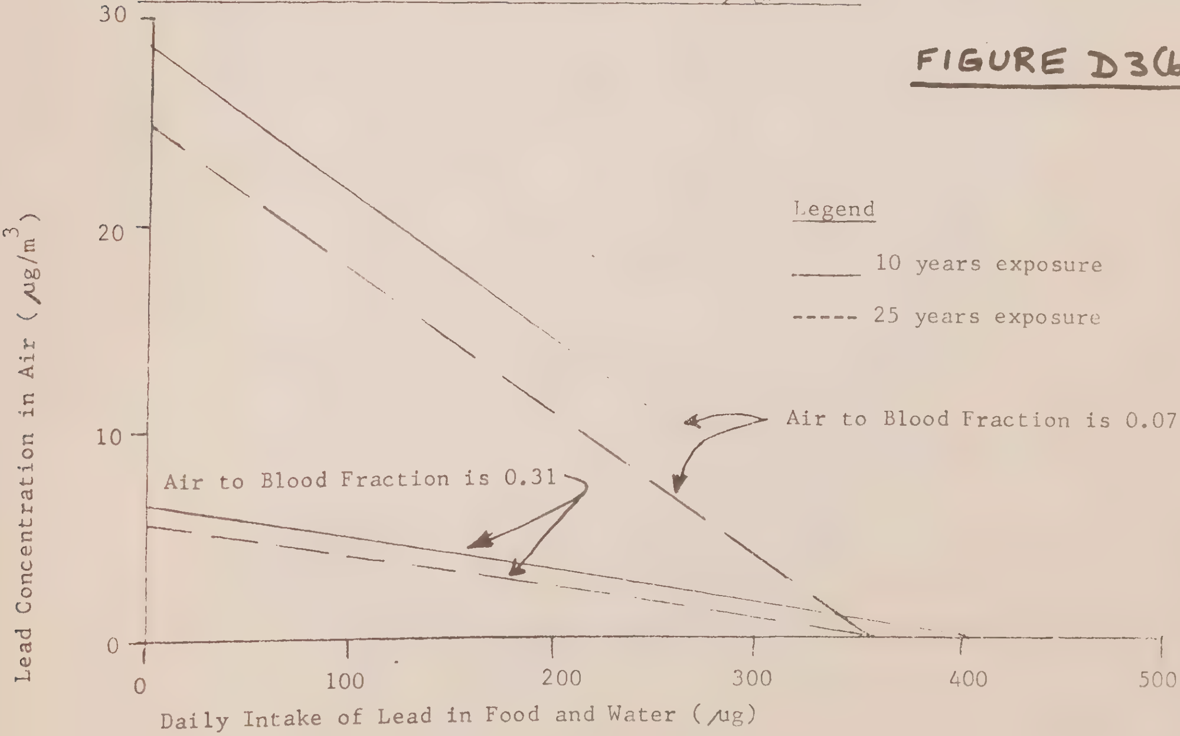
RELATIONSHIP BETWEEN DAILY INTAKE IN FOOD AND WATER AND LEAD CONCENTRATION IN AIR TO PRODUCE A BLOOD LEAD LEVEL OF 15 µg/100 ml

FIGURE D3(a).



RELATIONSHIP BETWEEN DAILY INTAKE IN FOOD AND WATER AND LEAD CONCENTRATION IN AIR TO PRODUCE A BLOOD LEAD LEVEL OF 30 µg/100 ml

FIGURE D3(b).



APPENDIX E

RESULTS OF SAMPLING IN TTC SUBWAY SYSTEM PREVIOUS TO OCTOBER '76 SURVEY

TABLE E1

ASBESTOS SAMPLING IN TTC SUBWAY SYSTEM

(May'75 and April '76)

Sample Description	Date	Total Asbestos Fibre Concentration* (fibres/ml)	Total Fibre Mass Concentration* ($\mu g/m^3$)	Concentration of Asbestos Fibres Longer than 5um* (fibres/ml)
Lawrence Station (South End)	22/5/75	1.6	.005	0.02
Lawrence Station (South End)	22/5/75	1.9	.025	N.D.
Yonge Station (East End)	20/4/76	1.7	.188	0.11 (0.16) (0.06)
Yonge Station (East End)	20/4/76	1.7	.011	0.04 (N.D.) (0.08)
Bloor Station (North End)	20/4/76	1.1	.029	0.07 (N.D.) (0.13)
Bloor Station (North End)	20/4/76	1.2	.017	N.D.
Lawrence Station (South End)	20/4/76	3.5	.204	0.31 (0.23) (0.38)
Lawrence Station (South End)	20/4/76	4.2	.031	0.17 (0.33) (N.D.)
Lawrence Station (South End)	20/4/76	3.0	.063	0.36 (0.46) (0.26)
Lawrence Station (South End)	20/4/76	3.3	.057	0.12 (0.23) (N.D.)
Dufferin Station (East End)	21/4/76	0.9	.115	0.04 (0.07) (N.D.)
Dufferin Station (East End)	21/4/76	0.9	.008	N.D.
Dufferin Station (East End)	21/4/76	1.5	.023	N.D.
Dufferin Station (East End)	21/4/76	1.0	.008	0.05 (0.09) (N.D.)

* = Mean of 2 determinations

N.D. = None Detected - The remainder of fibres in the percentage distribution.